



U.S. Army  
Environmental  
Center

# Amendment Selection and Process Monitoring for Contaminated Soil Composting

## FINAL REPORT

Report No. ENAEC-TS-CR-93109  
Contract No. DACA31-91-R-0009  
Task Order No. 01

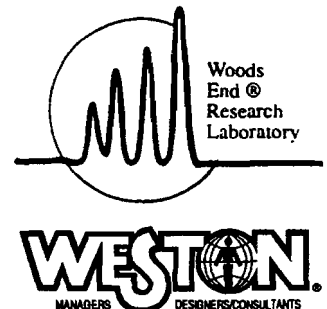
August 1994

*Prepared for:*  
U.S. Army Environmental Center (USAEC)  
SFIM-AEC-TSD  
Aberdeen Proving Ground, MD 21010-5401

*Prepared by:*  
Woods End Research Laboratory, Inc.  
1850 Old Rome Road  
Mt. Vernon, ME 04352

Roy F. Weston, Inc.  
1 Weston Way  
West Chester, Pennsylvania 19380-1499

94P-5206



REPORT DOCUMENTATION PAGE		Form Approved OMB No. 0704-0188	
<small>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.</small>			
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE August 1994	3. REPORT TYPE AND DATES COVERED Final, October 1992 - August 1994	
4. TITLE AND SUBTITLE  Amendment Selection and Process Monitoring for Contaminated Soil Composting		5. FUNDING NUMBERS	
6. AUTHOR(S) William F. Brinton, Ph.D. Eric Evans, M.S. Marg L. Droffner, Ph.D.			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  Woods End Research Laboratory      Roy F. Weston, Inc. Old Rome Road      1 Weston Way Box 1850      West Chester, PA 19380		8. PERFORMING ORGANIZATION REPORT NUMBER  963/02281-012-009	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)  U.S. Army Environmental Center SFIM-AEC-TSD Aberdeen Proving, MD 21010-5401		10. SPONSORING/MONITORING AGENCY REPORT NUMBER  ENAECS-TS-CR-8109	
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION/AVAILABILITY STATEMENT  Unlimited		12b. DISTRIBUTION CODE	
13. ABSTRACT - The U.S. Army Environmental Center (USAEC) has conducted field-scale demonstrations of composting technologies to treat explosives contaminated soils at the Umatilla Depot Activity (UMDA) in Hermiston Oregon. Development of composting for contaminated soils requires careful mixing of the soils with organic amendments of high enough respiration potential to support the development of thermophilic composting conditions. Amendment mixtures evaluated included several types of manures, food wastes and wood products. Bench-scale testing optimized mixtures based on porosity and thermophilic heating potential. Site-specific amendment testing and mixture formation was used to complement this process. This report presents the amendment selection methodology used for the UDMA demonstration projects. In addition, the results of compost process monitoring for factors which affect the compost operation are presented.			
14. SUBJECT TERMS  Composting, bioremediation, amendments		15. NUMBER OF PAGES	
		16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT  Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE  Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT  Unclassified	20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)  
Prescribed by ANSI Sta Z39-18  
Z98-102



## **Table of Contents**

SECTION 1 - EXECUTIVE SUMMARY .....	1 -1
SECTION 2 - INTRODUCTION .....	2 -1
SECTION 3 - THE COMPOSTING PROCESS .....	3 -1
SECTION 4 - BACKGROUND OF TNT COMPOSTING .....	4 -1
SECTION 5 - SITE AND PROJECT LAYOUT .....	5 -1
SECTION 6 - INVENTORY OF SOURCE MATERIALS .....	6 -1
SECTION 7 - SOURCE MATERIALS TEST SCOPE .....	7 -1
7.1 - MATERIALS AND METHODS .....	7 -1
7.2 - RESULTS .....	7 -7
7.3 - SOIL DENSITY TRIALS .....	7 -11
SECTION 8 - LAB RESPIRATION TRIALS OF INGREDIENTS .....	8 -1
8.1 - RESPIRATION RATE OF SOURCE INGREDIENTS .....	8 -1
8.2 - LABORATORY COMPARISON OF SOIL INFLUENCE .....	8 -6
8.3 - AMMONIA AFFECTS FROM MANURES .....	8 -10
SECTION 9 - BENCH-SCALE TESTING OF RECIPES .....	9 -1
9.1 - BENCH-SCALE DESIGN .....	9 -1
9.2 - BENCH-SCALE UNIT TESTING .....	9 -2
SECTION 10 - COMPOST RECIPE FINALIZATION .....	10 -1
SECTION 11 - COMPOST POROSITY FACTORS .....	11 -1
SECTION 12 - COMPOST PROCESS MONITORING .....	12 -1
12.1 - INITIAL TEST WINDROWS .....	12 -1
12.2 - STATIC SEED TANK MONITORING .....	12 -6
12.3 - FINAL CONTAMINATED WINDROW MONITORING .....	12 -9
SECTION 13 - RECOMMENDATIONS .....	13 -1
13.1 - PRE-TESTING INGREDIENTS .....	13 -1
13.2 - COMPOST INGREDIENT HANDLING .....	13 -1
13.3 - COMPOST PROCESS MANAGEMENT .....	13 -2
SECTION 14 - REFERENCES .....	14 -1

## **List of Tables**

Table 6-1 Agricultural Materials Found in North-East Oregon Suitable for Composting Ingredients .....	6 -2
Table 7-1 Selection Criteria for Source Materials for Contaminated Soil Composting Trials .....	7 -2
Table 7-2 Testing Protocol and Expected Ranges for Screening Compost Materials for Contaminated Soil Composting.....	7 -3
Table 7-3 Microbiological Testing Protocol (Proposed) and Expected Values for Screening Materials for Composting .....	7 -5
Table 7-4 Microbiological Testing Protocol for Description of the Composting Process .....	7 -6
Table 7-5 Biochemical Tests Evaluated for Description of the Composting Process .....	7 -8
Table 7-6 Laboratory Results for UMDA Source Ingredients - 1990 .....	7 -9
Table 7-7 UMDA Source Ingredients by Category 1991 - 1992 .....	7 -14
Table 7-8 Summary Lab Results for UMDA Source Ingredients 1990 - 1992.....	7 -17
Table 7-9 Relation of Volume to Weight and Effect of Soil Loading on Compost Bulk Density.....	7 -18
Table 7-10 Effect of Volume Loading on Soil Mass and Reduction on Water-Holding Capacity (WHC) and Ideal Moisture of Compost Piles.....	7 -19
Table 7-11 Organic Matter and Ash Content in Successive Compost Batches.....	7 -20
Table 7-12 Relationship of Feed (Recycle) Rate to Increase in Ash Content and Resulting Change in Soil Rate to Maintain Constant Conditions in Composting Using 10% Feed Rate.....	7 -20
Table 8-1 Composition of Selected UMDA Composts for Respiration Trials .....	8 -3
Table 8-2 Composition of Diverse Ingredient UMDA Compost Blends Tested in UMDA Respiration Trials.....	8 -5
Table 8-3 Potential Degradation of Soil Contaminants in UMDA Compost Mixes.....	8 -10
Table 9-1 Soil-Loading Influence on Observed Heating in Adiabatic Composter Units .....	9 -5

<b>Table 10-1 Prediction from Recipe and Actual Observed Values for</b>	
<b>Day 0 UMDA Composts .....</b>	<b>10 -2</b>
<b>Table 12-1 Laboratory Results - Initial Test Windrows .....</b>	<b>12 -4</b>
<b>Table 12-2 Microbiological Traits of Initial Aeration-Test Windrows.....</b>	<b>12 -6</b>
<b>Table 12-3 Laboratory Results of Monitoring Static Compost Vessels .....</b>	<b>12 -7</b>
<b>Table 12-4 Microbiological Traits of Static Vessel Seed Study.....</b>	<b>12 -10</b>
<b>Table 12-5 Laboratory Monitoring Results - Final Composts.....</b>	<b>12 -11</b>
<b>Table 12-6 Microbiological Traits of Final Windrows .....</b>	<b>12 -12</b>
<b>Table 13-1 Target Active Compost Monitoring Traits.....</b>	<b>13 -1</b>
<b>Table 13-2 Target Active Compost Monitoring Traits.....</b>	<b>13 -2</b>

## **List of Figures**

<b>Figure 6 - 1 Location of Key Source Materials and Relative Distance from Compost Site .....</b>	<b>6 -4</b>
<b>Figure 8 - 1 CO<sub>2</sub> Respiratory Rate of UMDA Compost Source Materials.....</b>	<b>8 -2</b>
<b>Figure 8 - 2 CO<sub>2</sub> Respiratory Rate of Two UMDA Pre-Selected Compost Blends Without Added Soil .....</b>	<b>8 -4</b>
<b>Figure 8 - 3 Performance of Selected Compost Mixtures in Respiration Trials .....</b>	<b>8 -7</b>
<b>Figure 8 - 4 CO<sub>2</sub> Respiration for Composts with Increasing Rates of Soil.....</b>	<b>8 -8</b>
<b>Figure 8 - 5 Respiratory Rate of UMDA Compost Minus Soil After One Week .....</b>	<b>8 -9</b>
<b>Figure 8 - 6 Ammonia Loss Rate for Various UMDA Compost Blends Without Soil.....</b>	<b>8 -11</b>
<b>Figure 8 - 7 Ammonia Loss Rate for Various UMDA Compost Blends in Relation to Soil Content.....</b>	<b>8 -12</b>
<b>Figure 9 - 1 Plan of Adiabatic Composter Unit Used by Woods End Research Laboratory to Test Compost Mixtures for Contaminated Soil Composting .....</b>	<b>9 -3</b>
<b>Figure 9 - 2 Functional Control Diagram of Adiabatic Composter Unit Used by Woods End Research Laboratory to Test Compost Mixtures for Contaminated Soil Composting .....</b>	<b>9 -4</b>
<b>Figure 9 - 3 Temperature Performance of Compost Pre-Mixes in Adiabatic Composter Units.....</b>	<b>9 -6</b>
<b>Figure 9 - 4 Relationship of Soil Inclusion Rate in UMDA Compost and Average Temperature Above Ambient Attained Over 30 Days.....</b>	<b>9 -7</b>
<b>Figure 11 - 1 Oxygen Content in Relationship to Time After Windrow Turning of Active Contaminated Soil Compost .....</b>	<b>11 -3</b>
<b>Figure 11 - 2 Compost Air Volume as a Function of Simulated Pile Depth and Pile Management.....</b>	<b>11 -4</b>
<b>Figure 11 - 3 Compost Air Volume as a Function of Pile Management, Depth in Pile, at Simulated Depths .....</b>	<b>11 -5</b>
<b>Figure 12 - 1 Volatile Organic Acid Concentration in Windrows at Different Ages.....</b>	<b>12 -3</b>

## **SECTION 1**

### **EXECUTIVE SUMMARY**

Composting of soil that has been contaminated with TNT, RDX and HMX requires selection and adjustment of source ingredients in order to result in a successful process. Compostable source materials are likely to be required in large quantities and therefore a suitable and economic selection process is needed.

Woods End Research Laboratory conducted a series of tests and pilot trials in order to develop an amendment selection procedure and a means to optimize the soil inclusion rates. The basis for this study was the field composting pilot trials conducted at the Umatilla Depot Activity (UMDA) site by Roy F. Weston, Inc. (Weston, 1991; Weston, 1993). The strategy for amendment selection is to: identify and analyze mixed ingredients from a region; evaluate the qualities of individual materials and the impact of various amendment mixtures on soil rate, and the impact of the process technology on compost microbiology.

Results of the compost amendment survey demonstrated that a diverse range of material was available within a 60 mile radius of the compost site. Manure materials varied widely in analytical traits, as did food processing residues. There was less variability with hay and feeds and still less with wood products. The expected variability by season and year must be taken into account when formulating compost recipes. The most important traits selected for were C:N (carbon:nitrogen) ratio, texture and respiration potential.

Laboratory trials using the carbon-dioxide respiration method revealed that materials like food-processing residues had very high respiration potentials and could be used to favorably influence the composting process in terms of rate of decomposition and heat attained. Manures like poultry which were readily available performed well but induced rapid ammonification at high inclusion rates and were therefore diluted with dairy manure. Sawdust was a reliable source of organic carbon and was important to dry the relatively moist food and manure ingredients.

Optimization trials demonstrated the ability of favorable compost mixes to carry soil loads up to 30% by volume without detracting from quality. A special adiabatic bench-scale unit was tested and successfully predicted the differential heating potential of



the different blends with soils. Compost porosity tests revealed that textural integrity was significantly reduced with windrow turning, and was diminished to low levels by normal compaction in compost piles.

Compost monitoring methods, which included microbiological screening, did not indicate significant differences within treatments of compost seeding trials or when comparing aeration technologies. Screening results found large populations of aerobic and facultative anaerobic bacteria in all of the composts. Although reduced aeration initially resulted in production of fermentative compounds, including volatile organic acids, they disappeared rapidly after 2 to 3-weeks of composting. Bacterial tests indicated only very low counts of obligate anaerobes despite low O<sub>2</sub> readings in field tests. Thus, compost microbiology tests confirmed the diversity and resiliency of the compost process used.

## SECTION 2

### INTRODUCTION

Several munitions sites throughout the United States have sediment lagoons contaminated with trinitrotoluene (TNT), various nitramine explosives (HDX, RDX, or Tetryl), or with nitrocellulose propellants (Bongiovanni et al., 1984; Rajat et al., 1991). A variety of technologies have been proposed for site decontamination and restoration. Among these, biological remediation focuses on microbiologically enhanced degradation of explosives contaminated soils. The interest in biological approaches dates from about 1979 (Suler, 1979; Smith et al., 1980; Isbister et al., 1982; Doyle et al., 1986; Weston, 1988; Weston, 1993).

Biologically induced degradation has been demonstrated in laboratory composts, greenhouses and in pure culture, at rates which are consistent with microbial respiration in those systems. For example, white rot fungus, *Phanerochaete chrysosporium*, has been shown to degrade TNT and RDX in pure culture (Fernando and Steven, 1990) as it has also been demonstrated to decompose PAHs (Qiu Xiujin and McFarland, 1991; McFarland et al., 1989). Apparently, the degradation mechanism is largely an oxidative process. The anaerobic removal of TNT has also been demonstrated (Boopathy, 1993).

Previous and mostly earlier approaches to field remediation of explosives contaminated soils have focused on a variety of feasible technologies: incineration, alkaline hydrolysis, aqueous thermal decomposition, ultraviolet radiation, land-farming and composting (Noss and Chyrek, 1983-4; Rajat et al., 1991). Incineration is an expensive technology, although complete oxidation is theoretically possible. Alkaline hydrolysis is an acceptable process for nitrocellulose degradation. In land-farming the degradation rates may be slow (Weston, 1985). Composting has been thought suitable for lagoon sediment highly contaminated with TNT or RDX if aerobic, thermophilic conditions are used (Doyle et al., 1982).

The composting approach emphasizes an enhanced milieu for microbial growth with the idea that the greater populations and higher turnover rates will induce more rapid, or more complete, or both, forms of degradation or humification. Theoretical advantages in the composting procedure include the aerobic, oxidative nature of the pro-

cess which encourages mineralization and its apparent resistance to the toxic effects of hazardous wastes. However, composting requires substantial amounts of supplemental organic materials to provide the appropriate environment for high-rate decomposition. Furthermore, composting requires material-specific management and monitoring. This report concerns specific aspects of identifying and preparing suitable composting amendment mixtures and the scientific monitoring required to properly manage the composting process (Brinton & Droffner, 1994).

## SECTION 3

### THE COMPOSTING PROCESS

Composting differs essentially from other biodegradation approaches such as solid phase bioremediation in the following ways:

- The organic content is raised to high levels by addition of other ingredients;
- Rapid microbial combustion induces heat formation causing thermophilic microorganisms to multiply.
- The process is managed by controlled additions of air and moisture, and sometimes by frequent turning of the piles.

While the principle of composting is simple, the actuality of composting contaminated soils is more complex. It involves balancing large amounts of variable but compatible ingredients and management of moisture and oxygen levels which are constantly changing over time. Furthermore, the large increase of density and loss of pore space resulting from soil inclusion may adversely influence the composting outcome, in particular with regard to whether heating can be sustained and to what extent an aerobic environment is maintained. Thus, gross physical qualities must be manipulated and managed for physical, chemical and biological reasons.

It is estimated that contaminated soils at the Umatilla Depot Activity site contain approximately 2% organic matter (including the TNT, HMX, RDX and other trace explosives); actual analysis by Woods End Laboratory of uncontaminated soil around the washout lagoons showed 1.2% organic carbon, or about 2% organic matter<sup>1</sup>. With such a small amount of metabolizable organic content, the likelihood of building up a sufficiently large microbial population to effect thermophilic degradation at high soil-loading rates is certainly questionable. Furthermore, there is a need to manage the process for successful biotransformation since various pathways including both step-wise reduction and oxidative mechanisms may be involved in TNT degradation, but are not clearly understood. Consequently, a more involved process of selection, management and quality control are needed.

---

1. Organic-C x 1.72 = Organic Matter (Page, 1982)

Since composting implies a diverse set of factors of both a physical and biological nature, some definitions are in order. Composting is a process, in fact, where a variety of unicellular organisms, predominantly bacteria, degrade organic wastes. The bacteria that accomplish this degradation include mostly organisms with the ability to use oxygen as a final electron acceptor (aerobic). However, facultative anaerobes, which are capable of the above but also produce metabolic by-products, are also found in large numbers. Other organisms including obligate anaerobes (true anaerobes) may also be present in composts but generally perish or sporulate in the presence of oxygen. Finally, a group of aerotolerant anaerobic bacteria exist which are capable of growing in the presence of oxygen but produce metabolic by-products without oxygen being used as an electron acceptor.

Other aspects of the definition of composting as aerobic are complicated for biochemical reasons. For example, mineralization is defined as production of  $\text{CO}_2$  and water from organic compounds and is effected only by aerobes. However, heterofermentative activity by several organisms including anaerobes also produces  $\text{CO}_2$  in addition to compounds like  $\text{CH}_4$ , ketones, organic acids and alcohol (Moat, 1979). Theoretically, degradation of  $^{14}\text{C}$ -TNT could result in labeled  $\text{CO}_2$  without aerobic mineralization having been involved, but under circumstances not considered to be anaerobic. Thus, theoretically, TNT can be degraded not only under conditions that are aerobic or anaerobic but also simultaneously, in view of the varying microenvironments which apparently exist in composts. Presently, very few studies are available which would elucidate these interactions.

## **SECTION 4**

### **BACKGROUND OF TNT COMPOSTING**

Efforts to compost explosive and propellant contaminated soils at the field scale were initiated in projects at the Louisiana Army Ammunition Plant (LAAP) and the Badger Army Ammunition Plant (BAAP) in 1987 through 1989. The LAAP and BAAP projects focused on demonstrating the technical viability of the composting approach. Both involved the static-pile layout similar to the Beltsville Method (US EPA Manual, 1980). The simple layout utilized standardized ingredients such as commercial grade alfalfa and horse-feed, time-controlled aeration and simple checks on process quality via temperature measurements and moisture control. Additionally, the LAAP trials incorporated a comparison of high temperature (55°C) "thermophilic" composting and medium-temperature (30–45°C) "mesophilic" ranges. A quantitative model for deriving compost-mix formulas was not used nor was process monitoring included beyond temperature and moisture checking. Furthermore, as cost analysis based upon these studies revealed the soil-fraction used in composting is the most important factor controlling overall economics (Weston, 1989b), the need existed to optimize amendment selection to reduce their cost.

The UMDA composting projects expanded on the scope of previous work by adding an optimization procedure to determine appropriate compost mixtures from local available resources, as well as a monitoring model to describe the composting process. In addition, mechanically agitated in-vessel (Weston, 1990) and windrow composting (Weston, 1992) technologies were evaluated. The objectives stated for the Umatilla studies (Weston, 1991; Weston, 1993) which specifically involve this report include:

- Selection of optimal carbon sources and bulking agents;
- Determination of the highest loading rate of soil applicable to static pile and mechanically agitated in-vessel technology;
- Comparison of performance of mechanically agitated in-vessel vs. static pile technology;

- Evaluation of transformation rates in relation to augmenting with compost seed and control of operating parameters such as turning frequency and aeration rate;
- Determination of optimization of environmental parameters such as moisture, temperature, pH, and oxygen content.

## **SECTION 5**

### **SITE AND PROJECT LAYOUT**

The Umatilla Depot Activity (UMDA) compost project layout has been described in other reports (Weston, 1990; Weston, 1991). The site is located in a semi-arid environment on about 20,000 acres in Hermiston, Oregon.

In 1990 USAEC conducted an optimization field study to test two types of composting systems (Weston, 1990). These systems included:

- Aerated static pile tanks with positive flow aeration and temperature feedback control;
- Mechanically Agitated In-Vessel (Fairfield) tank digester for mixed composting.

The objective was to compare the two-systems where variables included different soil loading rates, different compost recipes and addition of compost inoculants (Weston, 1991).

In preparation for the composting project Woods End Research Laboratory was contracted to develop suitable compost recipes with source ingredients found in the area of the Umatilla base. The assumption was that the economics and versatility of explosives composting could be improved by developing a materials selection and compost recipe model suitable for use at this base, and also any other base, in relation to the region.

In order to satisfy the need to optimize compost recipes, several steps were needed, among them:

- Develop a list of regional agricultural activities which influence availability of compost source materials;
- Secure samples of pre-selected materials and perform laboratory analyses to fully characterize them;
- Develop model recipes and pre-test in bench-scale pilot setups before full-sale selection and implementation.



After the amendment selection process was completed, a series of steps were taken to address the testing and implementation of the chosen recipes:

- Bench-scale monitoring of compost test mix respiration;
- Design and construction of an adiabatic composter for bench scale tests in order to pre-determine efficacy of mixtures.

At the completion of this phase and start-up of the composting process, additional steps were taken to fulfill the need to monitor the process and evaluate it microbiologically:

- Compost process monitoring protocol to establish composting performance;
- Microbiological parameters to determine efficacy of various treatments.

## **SECTION 6**

### **INVENTORY OF SOURCE MATERIALS**

A composting project which does not rely on commercially purchased, standardized ingredients must be able to efficiently evaluate and assess local resources as replacements. The purpose of this study is to report on the resource inventory protocol developed for the UMDA study by Woods End. The compost project ultimately utilized regional-available materials at a significant cost savings to the project (Weston, 1991).

An inventory was made of agricultural and food-industry activities likely to produce organic residues within a 50–100 mile radius of the Hermiston site (see Table 6-1 and Figure 6-1). The list of potential ingredients was compiled and a testing protocol established to screen these materials. Samples were obtained and Woods End developed data for each of the potential compost ingredients. Following this, suitable materials were chosen for bench-scale testing. The following sections describe this process.

The Oregon Department of Agriculture (DoA) was contacted to obtain published information on agricultural activities (Oregon Dept. of Agriculture, 1989). Woods End and Weston evaluated the listed farm practices and visited the region to follow-up the report and identify the typical residues. Table 6-1 gives a compilation of potentially compostable materials identified through this process.

The regional evaluation identified agricultural and forestry by-products including fresh materials and waste products which are potential candidates for inclusion in composting. The data indicated that many of the ingredients are available within 10 miles of the Umatilla Depot Activity base, while some key ingredients are as far as 80 miles either east or west.

While the study identified other wastes, they were further distant than about 80 miles, at which point hauling costs rise steeply. Traveling beyond these distances may impose excessively high transportation costs. For reference, the city of Portland is 180 miles away. Sewage sludge biosolids were not included in the survey. These biosolids are certainly available in the local region. In at least one previous research trial, however, composting contaminated soil with a sludge/woodchip blend gave poor results (Doyle et al., 1986). Additionally, there are potential disadvantages to using sludges, including odor, pathogens, metal content and public perception.

**Table 6-1 Agricultural Materials Found in North-East Oregon Suitable for Composting Ingredients**

Raw Materials	Present Use and Disposition	Distance	Availability	Relative Amount
<u>Vegetable/Plant Residues</u>				
Alfalfa, Fresh	Hay + Silage	local	May-Oc	large
Alfalfa (spoiled)	Dumped / burned	local	May-Oc	moderate
Apple Residues and peel Cake	Cattle Feed	local-60mE	Sep-Apr	moderate
Asparagus pieces	Cattle Feed	local†	May	moderate
Carrots/Culls	Cattle Feed	local-60mE	All year	moderate
Corn Silage	Cattle Feed	local	All year	large
Corn Stalks/Stover	Cattle Feed	local	All year	large
Peas (Vines-Hulls)	Cattle Feed	local-40mE	June	large
Potato Sludge	Land Applied/Filled	local	All year	large
Potato Seed Culls	Land Applied/Filled	local	May-June	v. small
Onion/culls	Land Applied/Filled	local	Fall/Spring	large
Mint Silage	Mulch, Feed	local	All year	large
<u>Animal Manures</u>				
Buffalo Manure	Range spread	local	All year	small
Chicken Manure	Land applied & Sold	80mW	All year	large
Dairy Manure	On-Farm spreading	local	All year	small
Duck Manure	In pens	local	Seasonal	v. small
Feed-lot Manure	Feedlot stockpiled	local	All year	large
Horse Manure	Private use near stables	local	All year	small

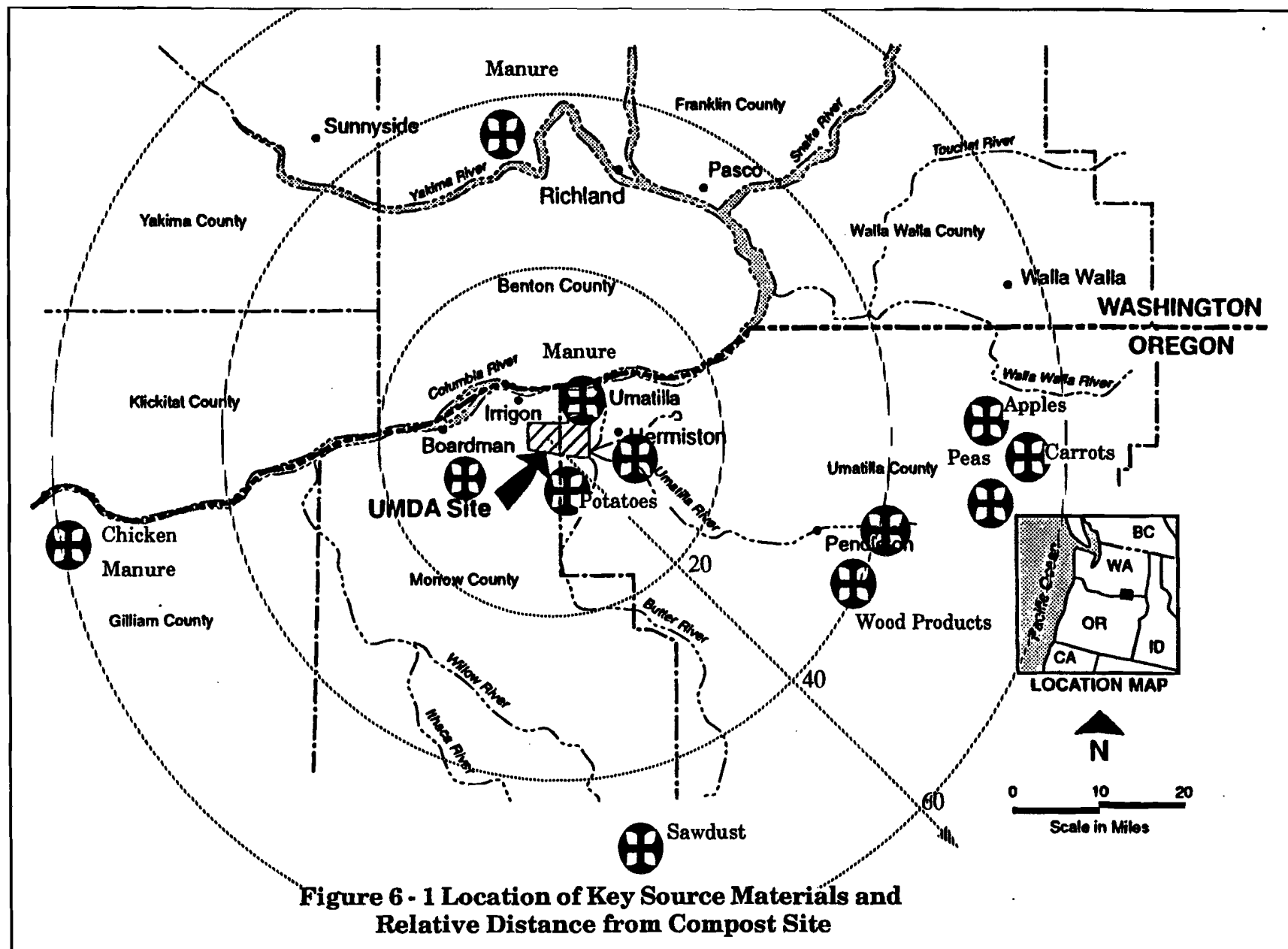
**Table 6-1 (Continued) Agricultural Materials Found in North-East Oregon  
Suitable for Composting Ingredients**

Raw Materials	Present Use and Disposition	Distance	Availability	Relative Amount
<u>Woods Products</u>				
Woods Splinters	Land applied/bedding	30mE	All Year	small
Chipped Wood	Paper plant	local	All Year	large
Sawdust	Paper	local-30-70mE	All year	large

KEY: † Local = within 10 mile radius of base; (m) = miles; (W) west, (E) east, etc. Small ≤ 100 tons per site/season. Moderate 100–1000 tons. Large >1000 tons

The data on available materials clearly indicates that relatively large amounts of food & fiber type materials exist in the area for composting. On the other hand, lesser and more variable amounts of manures exist, or in the case of a large amount of one type of manure, the supply is more distant. Each region will have its unique waste stream composition. The inventory data underscore the importance of a materials management protocol being established prior to undertaking a composting project.

The data presented in Table 6-1 does not fully reflect seasonality of production and business decisions which influence availability. Also, not all operators of farm enterprises are able to discuss their waste by-products or certainly could not predict long-term availability. During the 3 years in which the UMDA field tests were conducted, considerable variability of the quantities and availability of materials was experienced. For example, at least two providers of manure by-products for composting went out of production in this period.



## **SECTION 7**

### **SOURCE MATERIALS TEST SCOPE**

While it is theoretically possible to compost with single-source ingredients, it is generally held that effective composting requires a basic blending of different types of materials. The blending of available materials achieves several results:

- provision of sufficient bulk-porosity to enable adequate aeration for aerobic composting;
- provision of metabolizable energy in the form of carbon-rich matter;
- provision of adequate moisture and nutrients to support microbial generation.

All these traits are compromised to some extent by inclusion of contaminated soil which does not fulfill any of the above criteria. Consequently, selecting the appropriate materials and testing in advance to identify and confirm traits is important for successful soil composting.

Based on the resource inventory, samples were obtained of materials for which availability was certain for the period of the pilot project. Before obtaining samples, materials were evaluated to determine those most acceptable as compost ingredients.

The following table (Table 7-1) gives general guidelines on key traits used to pre-select potential compost ingredients. Pre-selecting compost ingredients based on this table does not necessarily prove they will be acceptable. Pre-testing to confirm desired traits is employed. Recommendations are offered here as to what tests or quick procedures can be applied to efficiently and rapidly evaluate and pre-screen materials.

#### **7.1 MATERIALS AND METHODS**

Compost source material samples are obtained by collection of representative materials. Previous work has identified aspects of sample collection and preparation for pre-testing contaminated soil compost materials (USGS, 1992). Precollection and analysis of compost source materials applied generally-accepted procedures (Page, 1982; US EPA, 1986; Greenberg et al., 1992; Horwitz, 1992). Presently, there are no standardized protocols to analyze compost source materials. It is customary to adapt waste water methods for compost ingredients. Several materials were examined in

this study which were essentially food by-products. It is generally held that testing these ingredients may be similar to analyzing agricultural product materials with methods similar to those found in AOAC manuals (Horwitz, 1992).

**Table 7-1 Selection Criteria for Source Materials for Contaminated Soil Composting Trials**

Ingredient	Key Traits	Limitations
<u>MANURE:</u>		
Cattle Manure	Med C:N High Microbes	VOA, high moisture
Chicken Manure	High N, Lime Content	pH, Ammonia
Pig Manure	Liquid application	Odor, Supply
Horse Manure	Med/high C:N, Loose texture	Variability of bedding
<u>VEGETABLE MATTER:</u>		
Alfalfa Hay	Coarse Texture, Nitrogen	Dust, mold, loss of texture
Potato Culls	High Available Energy	Variability, VOA , moisture
Apple Pomace	High Available Energy	Availability, pH
Mint Silage	High Available Energy	Availability
<u>WOOD MATERIAL:</u>		
Wood Splinters	Mixed/Coarseness	Supply
Wood Chips	Very Coarse Texture	Need final screening
Sawdusts	Fine texture, High C:N	Variability, Moisture, Supply

Table 7-2 outlines the protocol for screening source materials as applied in the course of the UMDA project. Expected ranges are given for each attribute and the appropriate analytical reference which provides methodology. The ranges bracket levels expected for source ingredients and active composts made from them which contain contaminated soil, based on UMDA data. Materials which fall outside the indicated ranges would be considered highly atypical and potentially problematic. This does not mean that all values that fall within the brackets are suitable for composting. It is the average composition after mixing all ingredients that determines suitability.

**Table 7-2 Testing Protocol and Expected Ranges for Screening Compost Materials for Contaminated Soil Composting**

<b>Attribute Examined</b>	<b>Summary of Rationale and Result for Test Indicated</b>	<b>Expected Range &amp; Unit</b>	<b>Method(s) Reference</b>
Total Solids (TS)	Establishes moisture and dry matter content	0-70% FS FS=fresh solids	(US EPA, 1986; Greenberg et al., 1992)
Water Holding Capacity (WHC)	Establishes water holding capacity which determines ideal moisture levels	50-250% TS TS = total solids	(Page, 1982; Horwitz, 1992)
Bulk Density (BD)	Establishes volume unit weight and porosity which influences shrinkage and air flow potential	600-1400 lb / yd <sup>3</sup> FS	(Horwitz, 1992; Page, 1982)
Total Nitrogen (TKN)	Establishes most important nutrient need for balancing with total carbon	0.3-4.5% TS	(Page, 1982; Greenberg et al., 1992; Horwitz, 1992)
Organic Matter†	Establishes total carbon (volatile solids x 0.54) from which assumptions about respirable energy potential are made	15-99% TS	(US EPA, 1986; Greenberg et al., 1992)
Oxidation-Reduction Potential (ORP)	Establishes balance of oxidizing and reducing factors influenced by rate of decomposition and air supply	-150-350mV FS	(Greenberg et al., 1992)
Carbon to Nitrogen Ratio (C:N)	Indicates nutritional balance based on ratio of total organic carbon : total nitrogen	12-45‡	(Page, 1982; Greenberg et al., 1992)
pH	Establishes limits for microbial suitability or conditions requiring control	4.0-9.2	(Page, 1982; Horwitz, 1992)
Ammonium (NH <sub>3</sub> + NH <sub>4</sub> )	Identifies potential for N-loss and volatilization hazard	0.01-0.30 TS	(Page, 1982; Horwitz, 1992)
CO <sub>2</sub> -respiration rate	Establishes metabolic rate or respirable carbon potential	0.2-25% C / day <sup>-1</sup>	(Page, 1982)
Volatile Organic Acids (VOA)	Confirms products of anaerobic respiration	300-25,000 ppm TS	(Greenberg et al., 1992)

† Range observed from UMDA composts and ingredients.‡ High C:N products not included in range



In addition to physical/chemical screening, micro-biological tests are advisable. These procedures fall into the category of pathogen related and process control tests. Due to the highly variable nature of raw materials, there is little justification to suggest that compost source materials be subjected to extensive microbiological tests for the purpose of determining mix recipes; however, there may be cause to ascertain possible hazards to workers from presence of *Salmonella* or *E. coli* in manures and farm wastes which may pose health risks. The following table (Table 7-3) identifies microbiological pre-screening which is advisable but was not undertaken in the UMDA trials. Some of the traits were, however, measured in active composts (see Table 12-2). A discussion of microbiological and viral health hazards and regulatory limits for solid waste is provided in recent reports (US EPA, 1985; Berg, 1983; US EPA, 1993).

In addition to pathogen related tests as identified in Table 7-3 other tests to group bacteria by activity classes were employed in this study. An outline of this approach is seen in Table 7-4.

Testing composts for microbiological activity in the manner proposed from Table 7-4 is often not routinely performed in composting. In this study, the groups of aerobes, anaerobes and obligate anaerobes were examined. The objective of this testing was to distinguish organisms in terms of the type of respiratory activity. We selected this approach since the type of activity is valuable to interpret composting. For example, the presence of *Clostridium* would confirm anaerobic compost conditions which might result from inadequate aeration.

**Table 7-3 Microbiological Testing Protocol (Proposed) and Expected Values for Screening Materials for Composting**

Attribute Examined	Summary of Rationale and Result for Test Indicated	Expected Range & Unit	Method(s) Reference
<i>Clostridium</i> spp.	Indicates anaerobic development and potential presence of pathogenic viruses, protozoa and worms	$10^2$ – $10^5$ cfu / g <sup>-1</sup> FS†	(Cabelli, 1977)
Coliforms	The presence of coliforms suggests fecal contamination and the presence of a variety of pathogens	$10^2$ – $10^7$ cfu / g <sup>-1</sup>	(Hajna and Perry, 1943; US EPA, 1985; US FDA, 1986; Greenberg et al., 1992; US EPA, 1993)
Fecal Coliforms	Coliforms which grow at 44.5°C producing gas which suggests fecal contamination	$10^2$ – $10^3$ cfu / g <sup>-1</sup>	(Hajna and Perry, 1943; US EPA, 1985; US FDA, 1986; Greenberg et al., 1992; US EPA, 1993)
<i>E. coli</i>	Suggests human pathogen contamination. This is a test for presence of the enzyme glucuronidase but does not include the virulent strain of hemorrhagic <i>E. coli</i> 0157:H7 nor the pathogen Shigella	$10^2$ – $10^4$ cfu / g <sup>-1</sup>	(US EPA, 1985; US FDA, 1986; Greenberg et al., 1992)
<i>Streptococcus fecalis</i>	The presence of this organism suggests fecal contamination and the presence of viruses	$10^2$ – $10^5$ cfu / g <sup>-1</sup>	(US EPA, 1985; US FDA, 1986; Greenberg et al., 1992)
<i>Salmonella</i> spp.	Salmonella is associated with pathogen contamination from food-animal material sources	$10^0$ – $10^3$ cfu / g <sup>-1</sup>	(Wilson et al., 1990; Curiale et al., 1990; US EPA, 1985; US FDA, 1986)

† FS = fresh solids (wet weight); cfu= colony forming units

**Table 7-4 Microbiological Testing Protocol for Description of the Composting Process**

Biological Activity	Organisms Involved & Measured	Expected Range & Unit	Method(s) Reference
Aerobic Respiration- (includes facultative anaerobes). Use oxygen as electron acceptor	<i>Pseudomonas</i> spp. <i>Bacillus</i> spp. (Aerobes) <i>E. coli</i> , <i>Salmonella</i> spp., <i>Klebsiella</i> spp., <i>Vibrio</i> spp., <i>Legionella</i> spp. <i>Yersinia</i> spp. <i>Erwinia</i> spp. <i>Enterobacter</i> spp., <i>Proteus</i> spp. (facultative anaerobes)	$10^2$ – $10^9$ cfu / g <sup>-1</sup> FS†	(US EPA, 1985; US FDA, 1986; Greenberg et al., 1992)
Aerobic Fermentation tolerate oxygen but do not use O <sub>2</sub> as electron acceptor	<i>Streptococcus</i> spp., <i>Staphylococcus</i> spp., <i>Enterococcus</i> spp.	$10^2$ – $10^4$ cfu / g <sup>-1</sup>	(US EPA, 1985; US FDA, 1986; Greenberg et al., 1992)
Anaerobic Respiration- includes obligate (true) and facultative anaerobes do not tolerate oxygen, produce organic by-products, incomplete degradation, little or no heating	<i>Campylobacter</i> spp., <i>Clostridium</i> spp., <i>Bacteroides</i> spp., (obligate anaerobes) <i>E. coli</i> , <i>Salmonella</i> spp., <i>Klebsiella</i> spp., <i>Vibrio</i> spp., <i>Legionella</i> spp. <i>Yersinia</i> spp. <i>Erwinia</i> spp. <i>Enterobacter</i> spp., <i>Proteus</i> (facultative anaerobes)	$10^2$ – $10^8$ cfu / g <sup>-1</sup>	(US EPA, 1985; US FDA, 1986; Greenberg et al., 1992)
Obligate Anaerobe Respiration Vegetative cells killed by oxygen	<i>Campylobacter</i> spp., <i>Clostridium</i> spp., <i>Bacteroides</i> spp.	$10^2$ – $10^5$ cfu / g <sup>-1</sup>	(Cabelli, 1977; US EPA, 1985; US FDA, 1986; Greenberg et al., 1992)

† FS = fresh solids (wet weight); cfu = colony forming units

Notes: facultative anaerobes appear in both the aerobic and anaerobic categories

A common method of grouping bacteria is Gram staining (Balous, 1991). However, Gram staining essentially distinguishes bacterial morphology and not activity. Therefore, it does not provide useful information to evaluate a biological process.

The microbiological processes and their efficacy can be surmised also from biochemical assays. In this project, selected enzymatic assays were undertaken as a means of analyzing the type of degradative activity rather than the organism. Such assays are

useful in that they are easy to perform and serve to qualitatively (and in some cases quantitatively) indicate important events. For example, the presence of urease suggests the formation of ammonia, a slightly toxic gas. Table 7-5 gives a schematic for enzymatic screening of the composting process.

In the course of the project, other assays were applied which also relate to interpretation of biological condition rather than measuring specific biochemical or microbiological traits. These included measuring temperature and oxygen content in the piles and volatile organic acids (VOA) with a special test-gel method (Woods End Research Laboratory, 1993).

## **7.2 RESULTS**

Source materials for UMDA compost trials were subjected to the set of tests indicated, and the results are displayed by category and by year in Table 7-6 and Table 7-7.

Sample data are presented for all the source ingredients which were tentatively selected for composting. No attempt was made at the time of sampling to determine the relative quantity of each material. Thus, the averages shown within each sample group are simply database averages and have equal weight assigned regardless of availability.

A similar group of source ingredients were tested in 1991–1992 and the results are shown in Table 7-7. By testing in a subsequent year, it is possible to determine where sources of variance lie for individual traits within sampling groups. For example, in the 1990 samplings of manures, moisture was low and varied by about 50% over all the samples. However, in 1992, there was considerably less variation.

In Table 7-8 the data for the two successive years are compared. The comparisons are made on the basis of the unweighted means for samples collected within each of the specified groups. These data indicate that for traits like C:N there are no significant differences between the years (variations were within one standard deviation unit).

**Table 7-5 Biochemical Tests Evaluated for  
Description of the Composting Process**

Biochemical Trait	Characteristic Involved & Measured	Expected Range & Unit	Method(s) Reference
Anaerobic fermentation & gas Production	Anaerobic production of VOA	+ or -	(Balous, 1991; Farmer, 1985)
Anaerobic CO <sub>2</sub> production	CO <sub>2</sub> -gas released anaerobically	+ or -	(Balous, 1991)
H <sub>2</sub> S formation	Bacterial reduction of sulfur and compounds	+ or -	(Farmer, 1985, Darland and Davis, 1973)
N <sub>2</sub> formation	Denitrogenase catalyzed reduction of NO <sub>3</sub> to NO <sub>2</sub> and N <sub>2</sub>	+ or -	(Farmer, 1985)
Urease activity	Ammonia release by hydrolysis of urea	+ or -	(Farmer, 1985)
Deaminase Activity	Formation of pyruvic acid from deamination of phenylalanine	+ or -	(Farmer, 1985)
Dehydrogenase Activity	Anaerobic respiration by reduction of 2,3,5 triphenyl-2H-tetrazolium chloride (TTC)	+ or -	(Farmer, 1985; Casida, 1964)
Hydrolase	Degradative activities of lipids, proteins by fluorescein di-acetate (FDA) hydrolysis	+ or -	(Farmer, 1985; Schnürer, and Roswall, 1982)
Cellulase	Degradation of cellulose measured by increase of reducing sugar groups	+ or -	(Farmer, 1985; Jue and Lipkje, 1985)

Notes: (+) or (-) refers to procedures which give a positive or negative only reactions.

**Table 7-6 Laboratory Results for UMDA Source Ingredients - 1990**

Material	H <sub>2</sub> O	pH	OM	TKN	C:N	NH <sub>4</sub> -N	ORP	Salt	CO <sub>2</sub> -C
	—as is—		—% TS—		Ratio	% TS	mV in/out	mmhos /cm	% of C <sub>t</sub>
<b><u>Animal Manure Ingredients</u></b>									
Buffalo Manure	18.2	8.53	81.29	1.83	25.7	0.005	<del>484</del> 410	0.8	3.15
Duck Manure	22.5	8.90	35.97	2.15	9.7	0.355	<del>395</del> 105	7.7	9.03
Chicken Manure	24.1	9.04	48.28	3.02	9.3	0.515	<del>392</del> 0	10.5	7.04
Horse Manure	48.0	8.84	82.97	2.60	18.5	—	<del>391</del> 263	5.7	—
Buffalo Manure	53.4	8.51	76.83	2.04	21.8	—	<del>434</del> 234	1.0	2.38
Cow Manure	63.2	7.01	45.26	1.95	13.5	—	<del>102</del> 66	19.4	3.89
Cow Manure	7.2	9.17	15.89	0.63	14.7	—	<del>360</del> 212	0.1	0.85
Chicken Manure	29.4	8.59	44.42	4.18	6.2	—	<del>17</del> -33	2.8	4.88
Chicken Manure	57.2	7.02	68.62	4.60	8.7	—	<del>256</del> 37	9.6	2.34
Horse Manure	45.4	9.43	87.41	0.95	53.6	—	<del>353</del> 293	1.6	—
Buffalo Manure	55.4	8.41	73.54	1.49	28.7	—	<del>389</del> 319	0.8	—
Horse Bedding	68.2	9.09	74.47	1.45	29.8	—	<del>356</del> 268	3.2	—
MEAN:	41.0	8.55	61.25	2.24	20.0	0.292	<del>327</del> 180	5.3	4.20
SD :	19.9	0.78	22.53	1.20	13.3	0.261	<del>137</del> 142	5.7	2.70

**Table 7-6 (Continued) Laboratory Results for UMDA Source Ingredients - 1990**

Material	H <sub>2</sub> O	pH	OM	TKN	C:N	NH <sub>4</sub> -N	ORP	Salt	CO <sub>2</sub> -C
	—as is—		—% TS—		Ratio	% TS	mV in/out	mmhos /cm	% of C <sub>i</sub>
<b><u>Animal Feed/Hay Ingredients</u></b>									
Alfalfa	10.9	6.10	89.47	3.10	16.7	0.030	<del>383</del> 356	3.2	—
Horse Sweetfeed	10.7	4.79	90.98	1.74	30.4	0.013	<del>277</del> 223	10.4	1.66
Straw	7.6	7.43	88.18	0.73	70.5	—	<del>323</del> 246	2.2	1.86
Alfalfa Hay	7.7	6.39	90.49	1.04	50.3	—	<del>290</del> -101	3.5	3.62
Alfalfa	5.2	6.03	87.78	3.40	15.0	—	<del>246</del> 241	3.3	—
Horse Feed	5.8	5.54	94.64	1.63	33.7	—	<del>232</del> 213	0.3	—
Alfalfa	14.8	6.18	84.93	3.57	13.8	—	<del>292</del> 238	3.5	—
MEAN:	9.0	6.07	89.50	2.17	32.9	0.022	<del>292</del> 202	3.8	2.38
SD :	3.4	0.81	3.03	1.17	21.1	0.012	<del>50</del> 142	3.1	1.08

<b><u>Food Processing/Vegetable Ingredients</u></b>									
Vegetable Waste	72.3	3.96	94.93	2.99	18.4	0.012	<del>179</del> 162	1.5	7.15
Apple Pomace	92.6	4.04	93.05	2.10	25.8	0.061	<del>175</del> 143	1.4	24.33
Potato Waste	85.5	4.39	93.49	1.97	27.5	—	<del>217</del> 171	2.3	13.70
Potato Waste	83.0	4.50	76.79	1.05	42.3	0.067	<del>105</del> 135	0.9	12.10
Apple Waste	95.1	3.67	93.53	1.03	52.5	—	<del>196</del> 152	1.9	9.13
Pea Waste	83.6	3.94	72.60	3.65	11.5	—	<del>124</del> 70	4.8	5.37
Potato Waste	83.6	3.72	95.51	1.31	42.3	—	<del>165</del> 111	2.5	2.14
MEAN:	85.1	4.03	88.56	2.01	31.5	0.047	<del>166</del> 135	2.2	10.56
SD :	7.41	0.31	9.49	1.00	14.7	0.030	<del>39</del> 35	1.3	7.23

**Table 7-6 (Continued) Laboratory Results for UMDA Source Ingredients - 1990**

Material	H <sub>2</sub> O	pH	OM	TKN	C:N	NH <sub>4</sub> -N	ORP	Salt	CO <sub>2</sub> -C
	—as is—		— % TS —		Ratio	% TS	mV in/out	mmhos /cm	% of C <sub>i</sub>
<u>Wood Product/Sawdust Ingredient</u>									
Sawdust, plain	24.5	4.88	99.75	0.06	1018	—	$\frac{297}{244}$	0.2	0.07
Sawdust, plain	4.0	4.54	99.20	0.01	6251	—	$\frac{334}{233}$	0.1	0.07
Sawdust, chip	15.5	5.16	99.13	0.08	715	—	$\frac{295}{255}$	0.3	—
Sawdust, splin- ter	8.0	5.29	99.16	0.10	568	—	$\frac{322}{354}$	0.2	—
MEAN:	13.0	4.97	99.31	0.06	2138	—	$\frac{312}{272}$	0.2	0.06
SD :	9.0	0.33	0.30	0.04	2748	—	$\frac{12}{56}$	0.1	0.02

(—) indicates not analyzed; SD = standard deviation

However, it also indicates that moisture, total-nitrogen and respiration activity can show large variations. Thus, it is important to check samples close to the time of compost preparation.

Remarkable consistency in organic contents between sample groups by years is seen. Woods products, for example, showed very little variation in important traits, except in the case of moisture content. A high moisture on wood would be a problem since wood is partly used to dry out the very moist manure and food scrap (potato) fractions.

### **7.3 SOIL DENSITY TRIALS**

High soil loading for composting is desirable from the point of view of cost-effectiveness for processing. However, high loading may adversely influence the process. In fact, the primary limiting factor in composting contaminated soil is likely to be the relatively high density and low nutrient value resulting from soil inclusion. Therefore, this project determined that high soil loading was a concern.



Probable effects of soil loading rates on compost include the following:

- Soil fraction in the mixture contains virtually no labile, organic content and will significantly reduce organic content needed for thermophilic composting;
- Soil causes a large increase in weight of material, increasing the risk of compaction;
- Soil fills the available pore space reducing the aeration or oxygenation potential;
- Soil reduces the water-holding capacity of the compost so that perturbations in moisture availability are imminent, requiring less water addition more frequently.

In order to develop a soil-loading model suitable to evaluate the limitations imposed by soil inclusion, several factors must be considered. Among them are density, water holding capacity and pore-space reduction. The objective in the model is to determine and predict upper ceilings for acceptable performance in composting.

Table 7-9 provides computations to determine bulk density from soil loading. The calculations are based on measurements of a typical compost mix (Mix "B", Table 8-1) and typical soil. The resulting bulk density is rated based on generally accepted values for compost pre-mixes (Brinton and Seekins, 1988).

Table 7-10 expands on the calculations by providing conversions of soil volume loading to weight-basis loading as well as to water-holding capacity and desired moisture. UMDA compost mix "B" was used to determine initial values. The model was tested against a variety of volume blends and found to accurately predict conditions.

According to the data, a soil volume loading of 30% means a weight addition of 50%. The increase in soil volume results in a steady increase of bulk density whereby the values approach marginal levels (for fresh compost) at or around a 30% soil rate (v/v).

It was necessary to further refine the table to convert volume to weight basis mixtures and to ascertain the influence of soil loading on other important traits such as water holding capacity and estimated ideal moisture content. The data is presented in Table 7-10.

The data in Table 7-10 indicates several important aspects of contaminated soil composting. The conversion of soil volume to a weight (mass) basis underscores concern that moderate volume loadings by soil represent large mass proportions. For example, at 30% of soil by volume the compost has 72% soil on a dry weight basis. If inorganic (soil) content is raised above 30%, the likelihood of sustained heating of the compost mass may diminish significantly. There are no published data relating heat performance to compost organic solids content.

The second UMDA study tested recycling of seed compost in 20-day cycles (Weston, 1992). The relationship of re-feeding compost to successive compost batches is suggested by previous work where re-inoculation of acclimated organisms has improved bio-degradation (NAAP Report, 1992). However, the addition of recycle compost to a compost blend consisting of a pre-mix and contaminated soil is constrained by the rule of diminishing returns, in that the use of recycle adds increasingly to ash (inorganic) content and thus may reduce the level of contaminated soil that can be processed. In order to test the hypothesis before UMDA trials commenced, a series of computations were made.

A compost which is constantly decomposing will loose labile organic to the extent that its usefulness as recycle becomes limited. Prior to initiating seed studies, therefore, some computations were made to determine recycle value. In Table 7-11 the changes in organic content resulting purely from degradation of the base compost mix is calculated for a mix containing 30% soil, assuming 6 successive batches consisting of 20 days each. The data clearly indicate that after two or three batches, the relative value of the compost in terms of organic content is very limited. If such compost is used a recycle, it will increasingly contribute more to ash than to organic matter.

In Table 7-12 the increase in compost inorganic fraction as a result of recycling the compost/soil product (Table 7-11) at a 10% addition rate is calculated per each cycle of a six batch process of approximately 20 days each is given. In this case, recycle is taken from each successive batch.

The table shows that if a recycle rate of 10% is used, then the amount of soil volume will have to be progressively decreased in order to stay at the same organic content. For example, if a soil volume loading of 25% is used, the reduction required is from

25% down to 18.7% by the end of the sixth batch. The data in these tables is used purely to illustrate the described problem of potential loss in efficiency of a continuous batch recycle system. The table suggests caution in introducing large amounts of soil to successive batches of contaminated soil compost.

Ultimately, the procedure used in the second UMDA trial (Weston, 1992) was a 5% recycle rate whereby the inorganic contribution was more negligible. The procedure to introduce recycle into compost for UMDA is described elsewhere (Weston, 1992).

**Table 7-7 UMDA Source Ingredients by Category 1991 - 1992**

Material	H <sub>2</sub> O	pH	OM	TKN	C:N	NH <sub>4</sub> <sup>+</sup> N	ORP	Salt	CO <sub>2</sub> -C
	—as is—		—% TS—		Ratio	% TS	mV in/ out	mmhos /cm	% of C <sub>i</sub>
<b><u>Animal Manure Ingredients:</u></b>									
Cow Manure-a ‡	73.0	6.95	58.49	0.75	42.0	0.061	$\frac{174}{36}$	2.0	3.72
Cattle Manure-a	76.3	6.30	60.55	1.33	24.5	0.118	$\frac{340}{40}$	3.1	6.88
Cattle Manure-b	72.1	4.92	68.16	1.07	34.5	0.091	$\frac{346}{239}$	3.4	0.28
Cattle Manure-c	62.7	8.86	41.93	0.83	27.2	0.079	$\frac{436}{149}$	2.5	3.02
Cattle Manure-d	70.7	5.42	66.24	0.97	36.8	0.116	$\frac{299}{82}$	3.1	4.88
Cattle Manure-e	59.6	5.39	37.35	0.47	43.3	0.124	$\frac{306}{204}$	4.7	1.36
Cow Manure-b	76.1	6.38	79.31	1.15	37.4	—	$\frac{-145}{-58}$	2.8	—
Hen Manure	73.1	7.71	65.16	4.48	7.8	—	$\frac{-17}{-104}$	29.7	—
MEAN:	70.5	6.49	59.65	1.38	31.6	0.098	$\frac{217}{73}$	6.4	3.36
SD :	6.1	1.32	13.86	1.28	11.7	0.025	$\frac{201}{120}$	9.4	2.39

—letters in the table refer to multiple samples from similar sources

**Table 7-7 (Continued) UMDA Source Ingredients by Category 1991 - 1992**

Material	H <sub>2</sub> O	pH	OM	TKN	C:N	NH <sub>4</sub> <sup>+</sup> N	ORP	Salt	CO <sub>2</sub> <sup>-</sup> C <sub>i</sub>
	— as is —		— % TS —		Ratio	% TS	mV in/ out	mmhos /cm	% of C <sub>i</sub>
<b><u>Food Processing/Vegetable Ingredients</u></b>									
Onion Shook	56.2	4.38	85.66	1.04	44.3	0.013	<del>192</del> 98	2.2	3.04
Apple Waste	92.1	5.15	94.70	1.02	50.1	0.014	<del>298</del> 256	1.2	0.10
Apple Pomace	78.5	4.72	93.60	1.26	40.1	0.002	<del>321</del> 350	0.5	2.61
Potato Cake	86.7	3.51	56.62	1.06	28.8	0.004	<del>158</del> 155	1.5	0.53
Potato Fries	85.8	4.40	95.53	1.17	43.9	0.042	<del>321</del> 170	2.0	1.79
MEAN :	79.9	4.43	85.22	1.11	41.4	0.012	<del>258</del> 206	1.4	1.61
SD :	14.1	0.60	16.46	0.10	7.9	0.016	<del>77</del> 98	0.7	1.28

<b><u>Animal Feed/Hay Ingredients:</u></b>									
Alfalfa Hay	10.1	7.90	85.08	2.95	15.6	—	<del>316</del> 208	9.8	—
Alfalfa Hay	29.3	8.45	79.21	3.43	12.5	0.110	<del>397</del> 170	5.2	0.59
Mint Silage	58.6	8.39	76.88	3.84	10.8	—	<del>328</del> 58	15.5	—
Pea Hay	38.0	6.90	89.68	1.37	35.4	—	<del>315</del> -39	5.2	—
MEAN :	34.0	7.91	82.73	2.89	18.6	—	<del>339</del> 99	8.9	—
SD :	20.1	0.71	5.79	1.08	11.4	—	<del>39</del> 112	4.8	—

**Table 7-7 (Continued) UMDA Source Ingredients by Category 1991 - 1992**

Material	H <sub>2</sub> O	pH	OM	TKN	C:N	NH <sub>4</sub> <sup>+</sup> N	ORP	Salt	CO <sub>2</sub> <sup>2-</sup> C <sub>1</sub>
	— as is —		— % TS —		Ratio	% TS	mV in/ out	mmhos /cm	% of C <sub>1</sub>
<u>Woods Product/Sawdust Ingredients:</u>									
Sawdust, plain	16.5	5.07	98.84	0.07	816	0.010	<u>344</u> 290	2.0	0.19
Sawdust, pin- e+fir	56.0	6.11	99.36	0.05	1095	—	<u>378</u> 305	0.2	—
Sawdust, pin- e+fir†	57.1	4.34	99.47	0.05	1061	—	<u>337</u> 233	0.4	—
Sawdust, hem- lock	17.2	5.07	99.86	0.04	1202	—	<u>382</u> 274	0.5	—
MEAN:	36.7	5.15	99.4	0.05	1044	—	<u>360</u> 276	0.7	—
SD :	22.9	0.73	0.45	0.01	163	—	<u>23</u> 31	0.8	—

SD - standard deviation  
(—) not analyzed;  
† aged pine+fir samples.

**Table 7-8 Summary Lab Results for UMDA Source Ingredients 1990 - 1992**

Material	H <sub>2</sub> O	pH	OM	TKN	C:N	NH <sub>4</sub> <sup>+</sup> N	ORP	Salt	CO <sub>2</sub> <sup>+</sup> C/C <sub>i</sub>
	—as is—			% dry basis result			mV in/out	mmhos /cm	%
<u>Animal Manure Ingredients</u>									
1990 MEAN:	41.0	8.55	61.25	2.24	20.0	0.292	<del>327</del> 180	5.3	4.20
1992 MEAN:	70.5	6.49	59.65	1.38	31.6	0.098	<del>217</del> 73	6.4	3.36
<u>Animal Feed/Hay Ingredients</u>									
1990 MEAN:	9.0	6.07	89.50	2.17	32.9	0.022	<del>292</del> 202	3.8	2.38
1992 MEAN :	34.0	7.91	82.73	2.89	18.6	—	<del>339</del> 99	8.9	—
<u>Food Processing/Vegetable Ingredients</u>									
1990 MEAN:	85.1	4.03	88.56	2.01	31.5	0.047	<del>166</del> 135	2.2	10.56
1992 MEAN:	79.9	4.43	85.22	1.11	41.4	0.012	<del>258</del> 206	1.4	1.61
<u>Wood Product/Sawdust Ingredient</u>									
1990 MEAN:	13.0	4.97	99.3	0.06	2139	—	<del>312</del> 272	0.2	0.06
1992 MEAN:	36.7	5.15	99.4	0.05	1044	—	<del>360</del> 276	0.7	—

( — ) not analyzed

**Table 7-9 Relation of Volume to Weight and Effect of Soil Loading on Compost Bulk Density**

Soil Or Compost Volume in Mix		Bulk Density	Value
Soil <sup>a</sup>	Com-post <sup>b</sup>	lb/yd <sup>3</sup>	(Rating)
0	100	945	acceptable
5	95	1018	acceptable
10	90	1091	acceptable
15	85	1164	acceptable
20	80	1237	acceptable
25	75	1310	acceptable-marginal
30	70	1382	marginal
35	65	1455	marginal to poor
40	60	1528	poor
45	55	1601	very poor
50	50	1674	very poor

<sup>a</sup> UMDA soil @ 1.42 g/cc bulk density

<sup>b</sup> Compost data based on Mix-B ingredients (see Table 8-1@ 0.56 g/cc.)

**Table 7-10 Effect of Volume Loading on Soil Mass and Reduction on Water-Holding Capacity (WHC) and Ideal Moisture of Compost Piles**

-----Soil Composition-----				Mix Bulk Density	WHC in % of	Ideal Moisture
Soil <sup>a</sup>	Compost <sup>b</sup>	as is	dry basis	lb/yd <sup>3</sup>	dry wgt <sup>c</sup>	% as is <sup>d</sup>
0	100	0.0	0.0	945	225.0	61.2 ok
5	95	11.8	24.2	1018	175.9	55.2 ok
10	90	22.0	40.3	1091	143.3	50.1 ok
15	85	31.0	51.7	1164	120.1	45.7 ok
20	80	38.9	60.3	1237	102.7	41.8 ok
25	75	45.9	66.9	1310	89.2	38.4 ok/marginal
30	70	52.1	72.2	1382	78.4	35.4 marginal
35	65	57.8	76.6	1455	69.6	32.8 m to poor
40	60	62.9	80.2	1528	62.3	30.4 poor
45	55	67.5	83.2	1601	56.1	28.2 v.poor
50	50	71.8	85.8	1674	50.7	26.2 v.poor

<sup>a</sup> Based on measured soil density of 89 lbs/ft<sup>3</sup> (1.42 g/cc) bulk-density

<sup>b</sup> Compost pre-mix of 61% water @ 0.56 g/cc bulk-density

<sup>c</sup> Compost @ 225% WHC and soil @ 22% WHC

<sup>d</sup> Based on assumption of 70% of WHC

Note: Compost used is Mix B, Table 8-1



**Table 7-11 Organic Matter and Ash Content in  
Successive Compost Batches**

ORGANIC MATTER %	ASH CONTENT %	Successive Batches @ 20days each
30.0 <sup>a</sup>	70.0	Run 1
22.5 <sup>b</sup>	77.5	Run 2
16.9	83.1	Run 3
12.7	87.3	Run 4
9.5	90.5	Run 5
7.1	92.9	Run 6

<sup>a</sup> Based on measured data for UMDA compost with 30% soil added

<sup>b</sup> Based on 25% loss of organic matter as determined from bench-scale 20 day runs.

**Table 7-12 Relationship of Feed (Recycle) Rate to Increase in Ash Content  
and Resulting Change in Soil Rate to Maintain Constant Conditions in  
Composting Using 10% Feed Rate**

Batch Sequence	Soil Wgt	Mix Wgt	Base % Ash	Feed Wgt	Blend %Ash	Vol Soil	Soil Rate To Maintain
Notes:	(a)	(a)	(b)	(c)	(d)	(e)	Same Inorg (f)
B1	46.0	54.0	66.7	0.0	66.69	25.0	0.0%
B2	46.0	44.0	77.6	10.0	74.02	29.0	-4.0%
B3	46.0	44.0	77.6	10.0	74.37	26.6	-4.5%
B4	46.0	44.0	77.6	10.0	74.63	27.2	-5.0%
B5	46.0	44.0	77.6	10.0	74.82	27.3	-5.6%
B6	46.0	44.0	77.6	10.0	74.97	27.4	-6.3%

**Notes to Table 7-12:**

(a) pounds in 100 lbs fresh wgt compost/soil blend

(b) the computed inorganic content without feed additions

(c) the mount of feed (recycle compost) in 100 lbs of soil/compost blend

(d) the inorganic level in compost after feed is added at specified rate

(e) Volume of contaminated soil as % of total compost

(f) The change in contaminated soil loading to counteract increase in Ash

## **SECTION 8**

### **LABORATORY RESPIRATION TRIALS OF INGREDIENTS**

Loading of compost with non-organic soil material acts to dilute the ingredients which are responsible for heating and active degradation. In composting contaminated soil, it is a primary objective to optimize the soil inclusion. Therefore, the need exists to maximize the degradation potential of the non-soil component. We measure this by evaluating the carbon-dioxide respiration rate of added ingredients.

A respiration quotient is the rate of CO<sub>2</sub> release relative to the mass of the included material. By increasing this as high as possible, the ability of the compost to carry a high soil-load is thereby maximized. Therefore, monitoring of source ingredients for respiration potential is an important selection tool, enabling operators to maximize soil through-put.

A series of laboratory trials were undertaken to evaluate the contribution of various selected compost ingredients to the overall compost-respiration process.

Three aspects were evaluated in these trials:

- Respiration quotient of all source ingredients;
- Respiration rate of blended (compost mix) source materials;
- Respiration rate of blended mixes as influenced by soil loading.

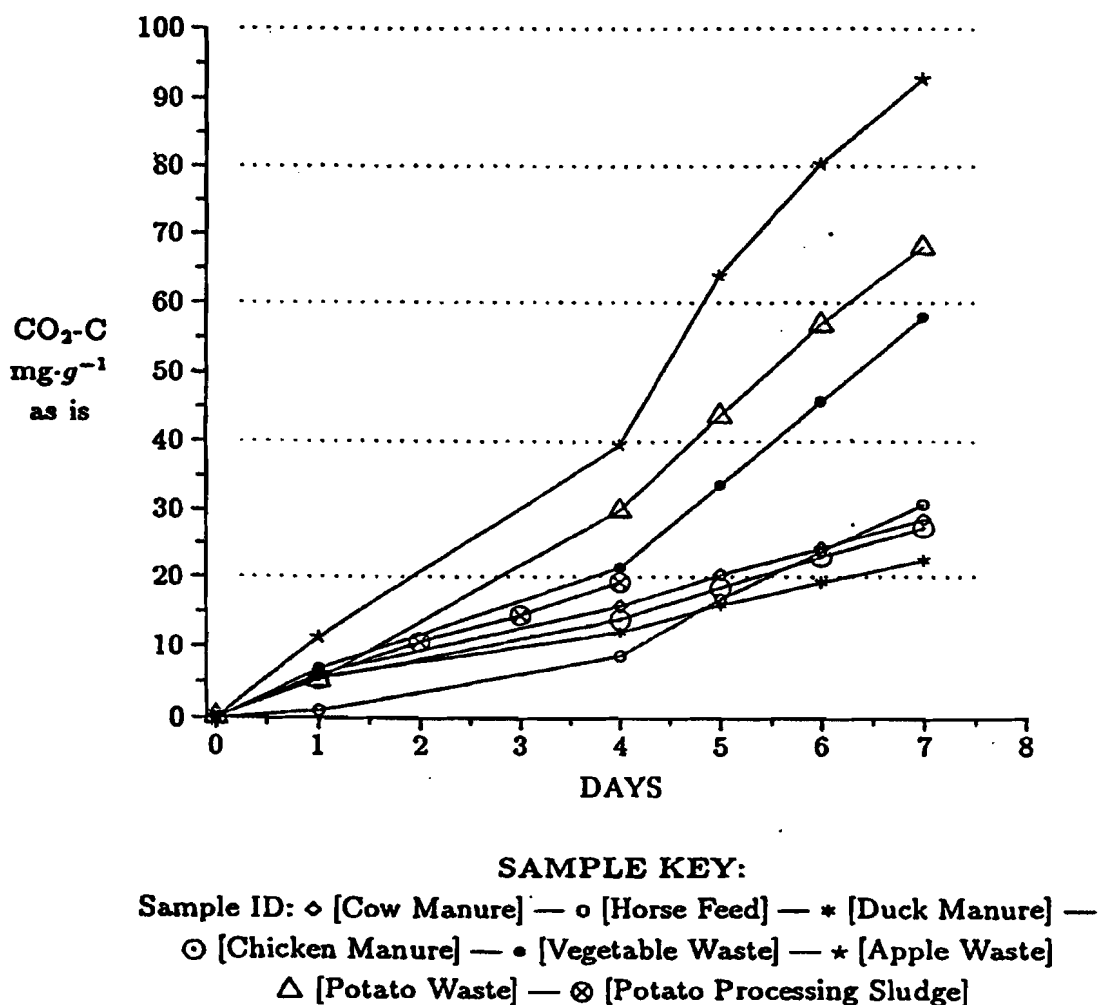
#### **8.1 RESPIRATION RATE OF SOURCE INGREDIENTS**

Separate source ingredients were evaluated for respiratory rate by preparing the sample in respiration jars where the only manipulation includes adjusting moisture to optimal levels (Page, 1982). Several regional wastes were selected as potential candidates for composting. The CO<sub>2</sub>-incubation results are shown in Figure 8-1.

Compost source materials showed respiratory quotients in the order Apple > Potato > Vegetable > all manures. The group of vegetable matter wastes averaged more than 3-times the cumulative carbon-dioxide than the manure group. This is not surprising since food wastes contain large proportions of simple carbohydrates which are readily utilized by microorganisms. It strongly supports the concept of utilizing food materials as inputs to composts which contain significant amounts of soil.

Pre-testing of source ingredients for carbon-dioxide release potential is useful to identify potential high performers for composting. Implicit in this project has been the assumption that materials showing high respiratory qualities are valuable for soil-composting.

**Figure 8 - 1 CO<sub>2</sub> Respiratory Rated of UMDA Compost Source Materials**



Conducting respiration trials of single ingredients is as a rule not recommended. This is because the materials are often very low or high in moisture, pH or other traits which may require adjustments to be made. Furthermore, the materials can vary in terms of microbial substrate suitability. Treating them separately can result in different behavior then when blending together later as in a compost.

In our trials of ingredients, we adjusted only to achieve optimal water, determined as 60–80% of the water holding capacity (WHC). However, unless the same manipulation of the material is practiced for composting the danger exists that the laboratory results will not compare with field experience. We therefore chose to prepare actual recommended compost blends and test them by the same respiration procedure.

Two groups of source ingredients were selected and prepared into test compost blends, as seen in Table 8-1. The mix “A” is typical of traditional composts with manure and sawdust as the principal ingredients with one added higher energy food ingredient (see Table 8-1). In contrast, mix “B” selects for more energy (based on respiration trials) with vegetable/food scrap and more available nitrogen in the form of poultry manure. Poultry manure had 3-times more nitrogen than horse manure tested in 1990 (see Table 7-6). Vegetable scrap and potato waste came in 2nd and 3rd in respiration trials next to apple pomace and were more available (see Figure 8-1).

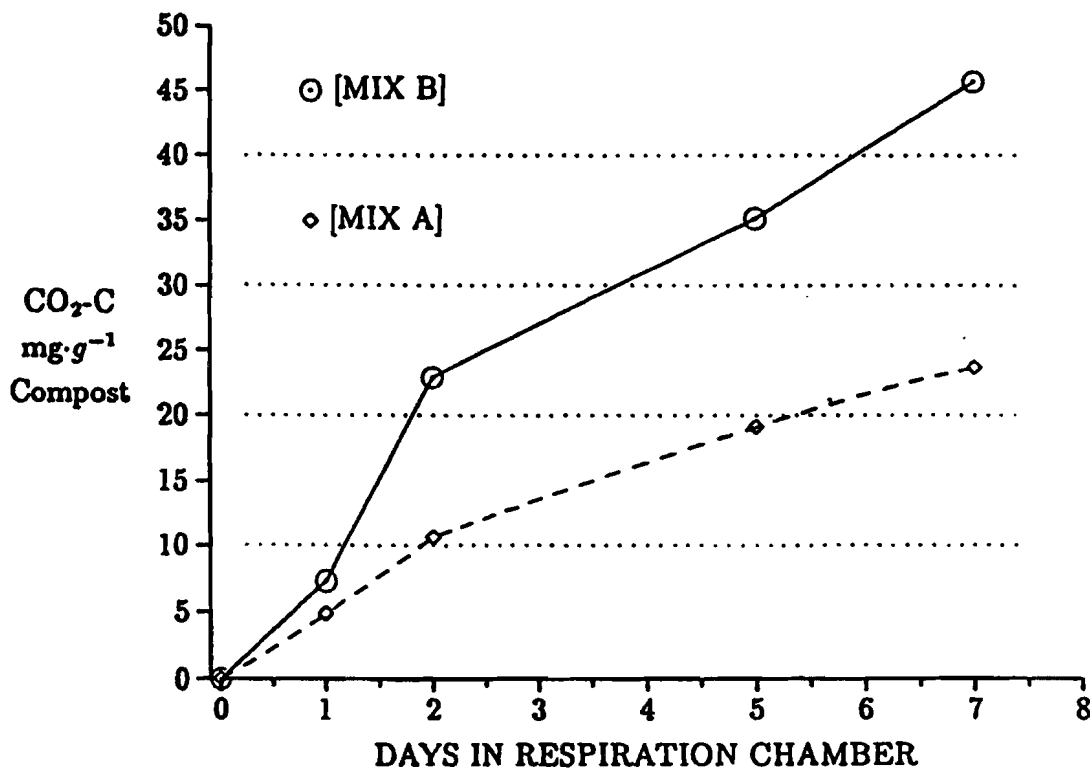
The two groups of selected ingredients or “recipes” were blended to achieve the same C:N ratio and moisture content. The target C:N was 35–40. In blending, we select first on C:N and secondly on moisture. The two groups were run in 7-day respiration trials to determine the total CO<sub>2</sub> potential. The results are graphed in Figure 8-2.

**Table 8-1 Composition of Selected UMDA Composts for Respiration Trials**

Ingredients Used In Compost Mix	MIX A	MIX B
	Fresh Weight Basis	
Sawdust	20%	30%
Horse Manure	44%	-
Apple Pomace	36%	-
Chicken manure	-	20%
Vegetable Scrap	-	15%
Chopped Potato	-	35%
<b>TOTALS</b>	<b>100%</b>	<b>100%</b>

There were no differences in the two composts in the first day of composting. After 2 days, the differences increased. The results of this trial indicate that the “improved” recipe out-performed the basic mix in terms of CO<sub>2</sub> respiration by almost a factor of two over 7 days. These data support the conviction that diverse blends of compost ingredients containing both high-energy, nutrient-rich ingredients may be superior for compost heat production.

**Figure 8 - 2 CO<sub>2</sub> Respiratory Rate of Two UMDA Pre-Selected Compost Blends Without Added Soil**



The recipe scheme was further refined by adding additional mixtures to the basic recipes “A” and “B”. These are identified in Table 8-2. The strategy included:

- Mix-2 Substituting apple pomace for vegetable scraps;
- Mix-3 Substituting horse manure for chicken manure;
- Mix-4 Substituting straw for half the sawdust;
- Mix-5 Alternate blend with reduced chicken manure;
- Mix-6 Substituting straw for half the sawdust in new blend.

The results of the respiration trials are shown in Figure 8-3. Only slight improvements to the performance of Mix B were achieved. Substituting apple pomace for vegetable scraps reduced the overall respiration, probably on account of the low pH of the pomace. When we split the bulking material (sawdust) with rye straw, no improvement was noticed (treatment 4 versus treatment 1).

Two potential problems regarding the recipes were noted. Chicken manure tends to produce large quantities of ammonia and needs to be slightly reduced. Also, apple pomace is readily available in the Oregon/Washington region and therefore it would appear to be useful to include it in future compost programs. The loss in some performance with apple pomace addition as noted in previous trials was re-examined. New mixes which slightly increased the content of bulking agent and reduced poultry manure were prepared with the idea of offsetting the high moisture of the pomace and vegetable scraps.

**Table 8-2 Composition of Diverse Ingredient UMDA Compost Blends Tested in UMDA Respiration Trials**

Ingredient to Compost	Mix 1 (B-Table 14)	Mix 2 (Alt-1)	Mix 3 (Alt-2)	Mix 4 (Alt-3)	Mix 5 New Mix	Mix 6 Alt-New
	<u>Fresh Weight % Basis</u>					
Hardwood Sawdust	30	30	30	15	46	23
Rye Straw	-	-	-	15	-	23
Horse Manure	-	-	20	-	-	-
Apple Pomace	-	15	-	-	12	12
Chicken Manure	20	20	-	20	15	15
Vegetable Scrap	15	-	15	15	-	-
Chopped Potato	35	35	35	35	27	27
TOTALS	100	100	100	100	100	100

The data in Figure 8-3 indicate further increases in respiratory rate with the adjustments. Cutting the bulking agent (sawdust) with hay or straw gave noticeable im-

provements. Thus, future recipes were based on splitting the bulking between sawdust and straw (see Weston, 1993). Ultimately, apple pomace availability was too seasonal for inclusion in the pilot UMDA investigation and was eliminated in favor of cull potatoes. Additionally, it was necessary to further dilute the chicken manure with cow manure as a result of high ammonification rate observed.

## **8.2 LABORATORY COMPARISON OF SOIL INFLUENCE**

The effect of adding soil to pre-selected compost blends was evaluated in a series of bench-scale respiration trials. We incubated the mixes from the previous trial (Figure 8-3 and Table 8-2) with soils up to 57% by wet weight (40% volume). The results computed to 7-days (cumulative CO<sub>2</sub>-C) are seen in Figure 8-4.

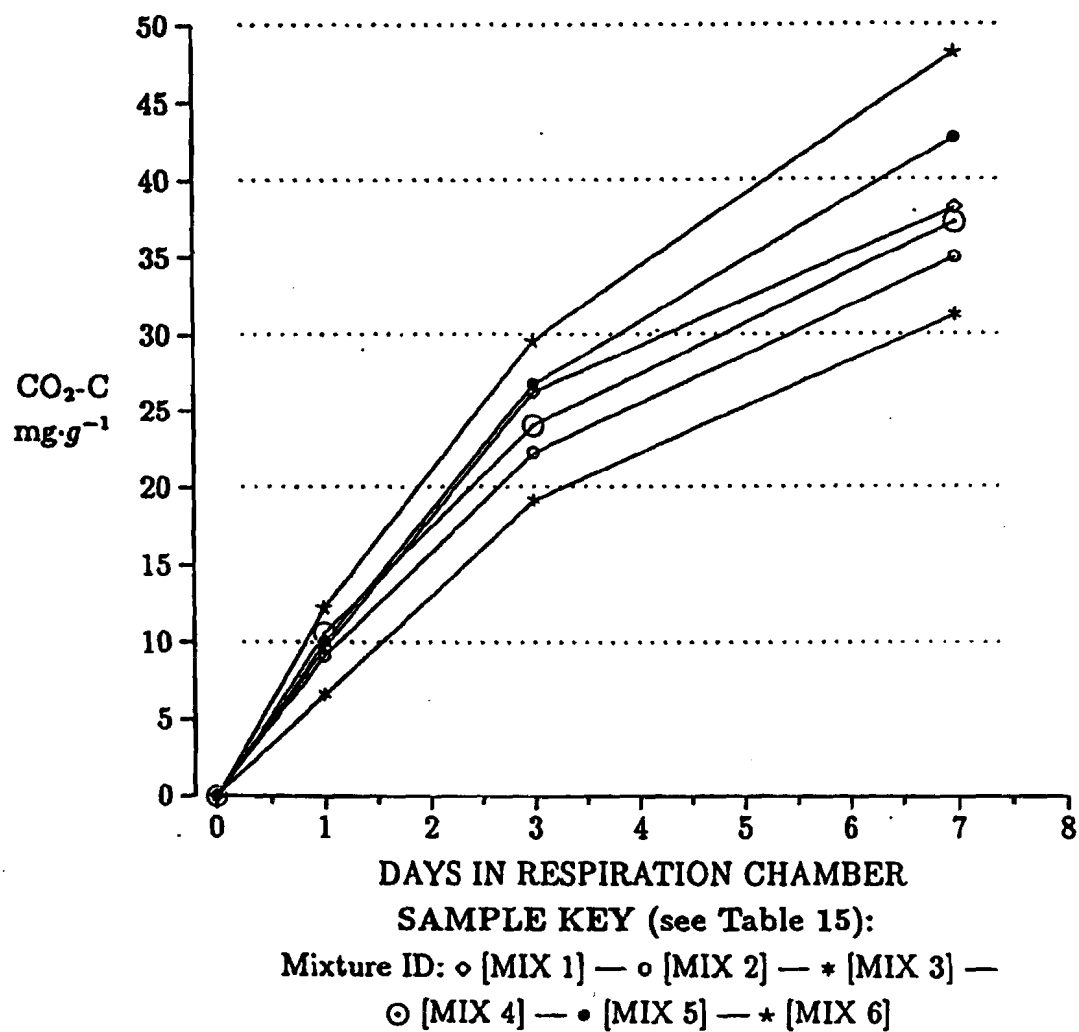
The data from these trials underscore the fact that different compost mixtures tend to behave increasingly similar as the soil rate increases and that the addition of soil causes a proportional reduction in respiration rate.

In accordance with the data in Figure 8-4, an increase in soil causes a significant reduction of carbon-dioxide respiration. Theoretically, the respiration should decline in exact proportion as the percentage soil increases (the amount of soil on a weight basis may be found from data presented in Table 7-10).

However, some of the data reveals that the rate of loss of respiration potential does not decline as fast as would be predicted from the soil inclusion percentage. Furthermore, the greatest decline occurs with small additions of soil; a curvi-linear relationship exists for some of the recipes (including Mix B and its alternates) so there may be a diminishing reduction evident at higher rates.

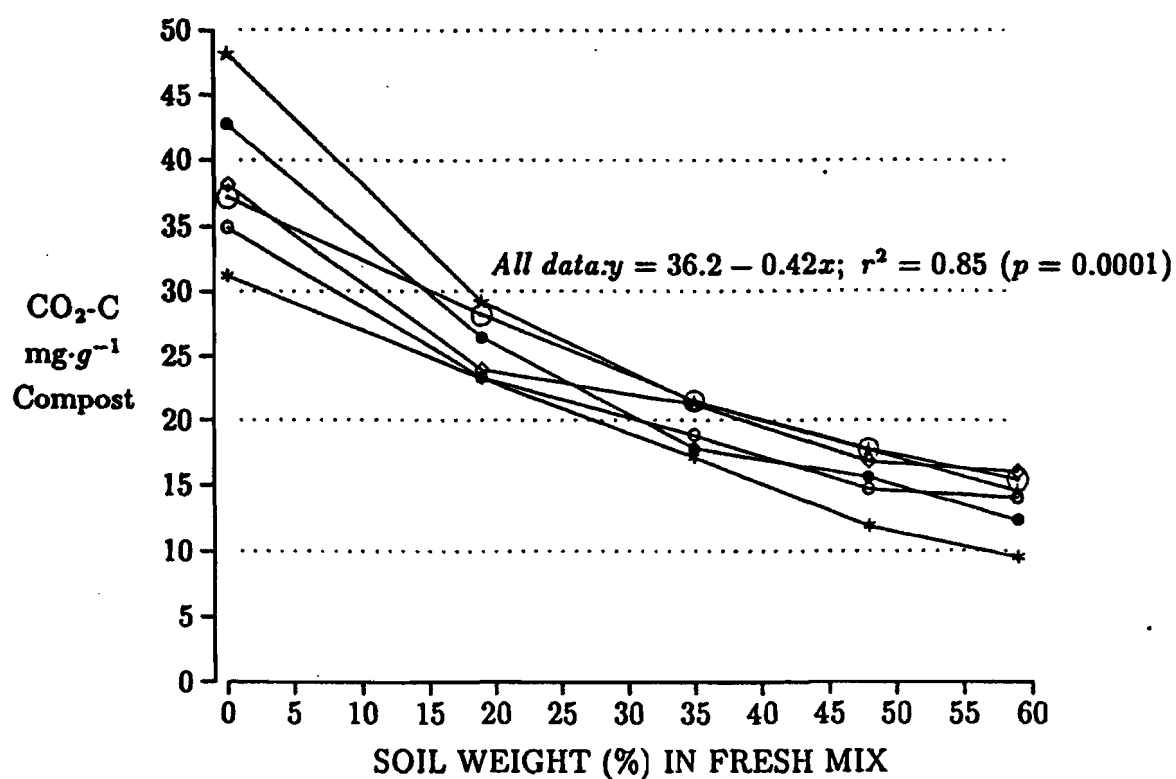
The factor of declining respiration was examined by adding soil to mix A and B at different rates and calculating the respiration in terms of original organic content (compost minus soil). These trials indicate that in the case of A the organic degradation rate was constant at all soil percentages, which theory predicts. In the case of mix B, the CO<sub>2</sub> rate increased per unit of organic matter with increasing soil volume (see Figure 8-5). Since there were no replicates we can not say if the effect is significant. However, the information is certainly hopeful since the goal of the project is to optimize soil loading to composts.

**Figure 8 - 3 Performance of Selected Compost Mixtures in Respiration Trials**





**Figure 8 - 4 CO<sub>2</sub> Respiration for Composts with Increasing Rates of Soil**

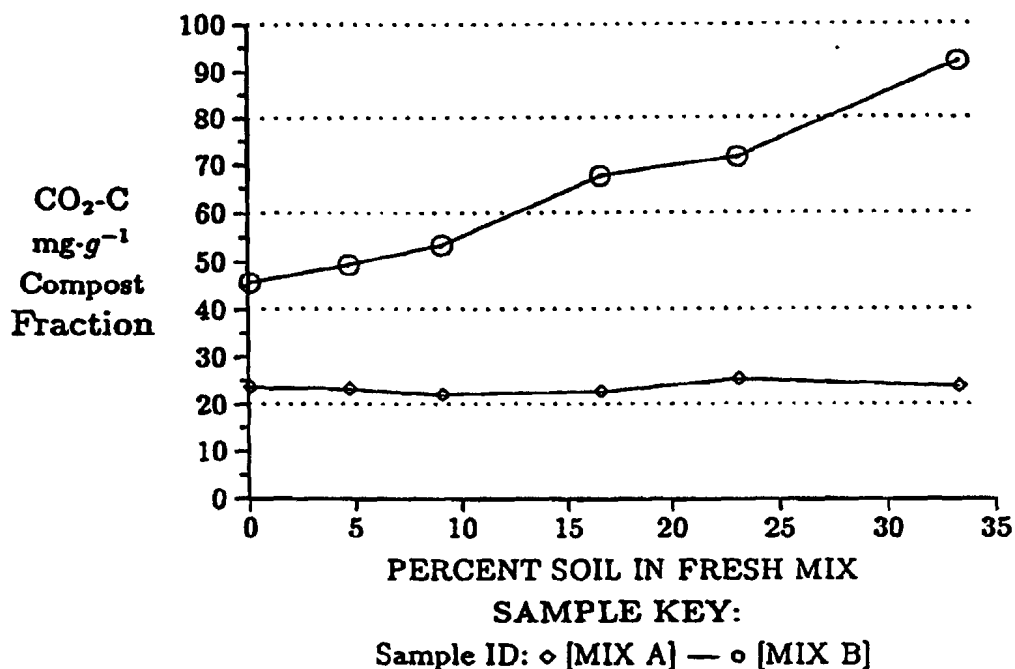


**SAMPLE KEY (see Table 15):**

Sample ID: ◇ [MIX 1] — ○ [MIX 2] \* [MIX 3] —

⊙ [MIX 4] — ● [MIX 5] — ★ [MIX 6]

**Figure 8 - 5 Respiratory Rate of UMDA Compost Minus Soil  
After One Week**



A variety of existent factors prevent this information from being extrapolated, however. For example, the trials were run at a constant temperature and therefore heat effects from varying respiration rates can not be examined. The observations do not allow us to determine at what percentage of soil loading organic matter degradation is optimized. Later studies (see Table 9-1) indicate a net loss in heating potential with increased soil rates.

The potential degradation of organic compounds in a soil-compost system can be defined as:

$$\text{Potential Degradation} \propto (\text{mg CO}_2\text{-C} / \text{g total mix})(\% \text{ of soil}) \quad (1)$$

where CO<sub>2</sub>-C is data from respiration trials of a compost mix. This equation can also be written:

$$\text{Potential Degradation} \propto (\text{Relative Heating})(\% \text{ of soil}) \quad (2)$$

Where relative heating is the difference of heating in a treated versus untreated sample from a self-heating adiabatic trial. Substituting the actual heating values measured from the adiabatic compost trials and soil loading in Equation 2 gives the results seen in Table 8-3.

**Table 8-3 Potential Degradation of Soil Contaminants in UMDA Compost Mixes**

Vol % Soil in compost Tested	Rel. Heating (Adiabatic) <sup>a</sup> (A)	% Soil by wgt. (see Table 11) (B)	Relative Soil Organic Degradation (A)(B)
0	100	0	0
10	105	22	2310 <sup>b</sup>
20	93	39	3627
30	66	52	3432

<sup>a</sup> See Table 7-11

<sup>b</sup> Arbitrary units.

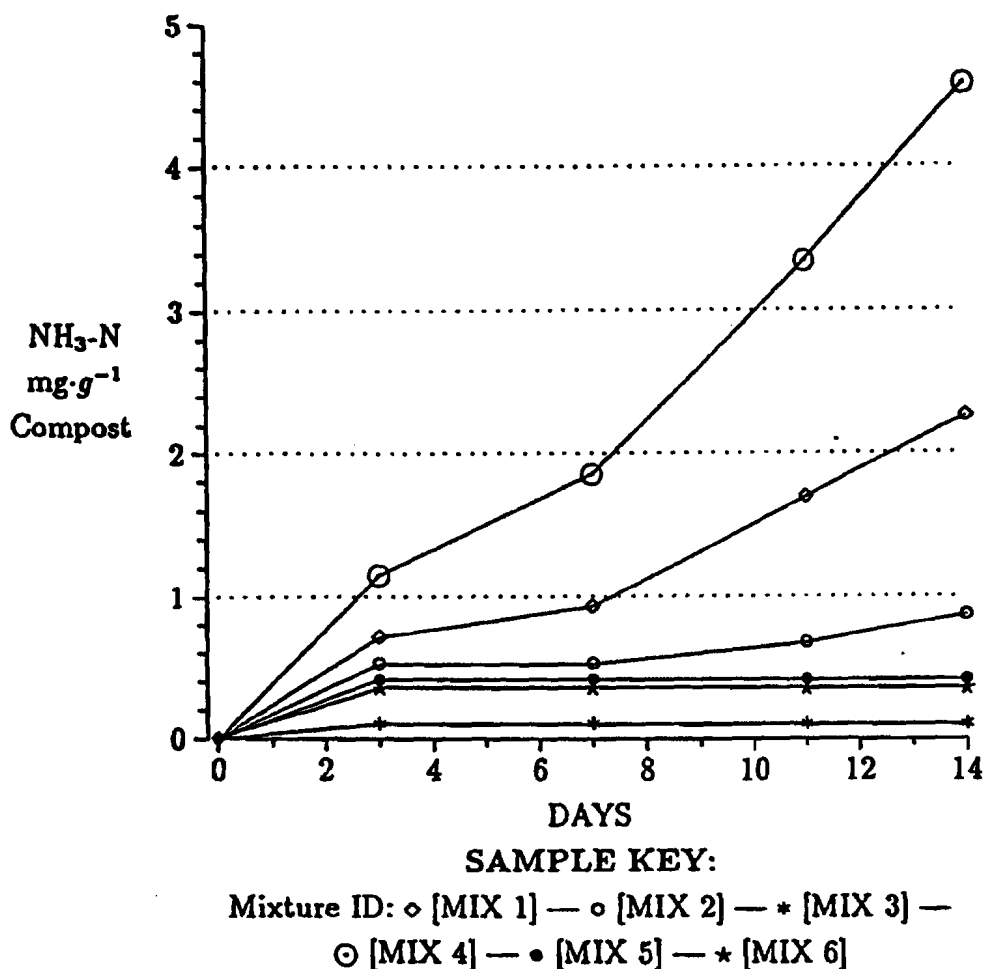
The data in Table 8-3 based on the equations 1 and 2 suggests that decomposition of contaminated soil peaked at the 20% soil volume rate but was no different at 30%, while both were significantly better than 10%. The data has not been extensively tested. It does suggest that a 20–30% contaminated soil inclusion rate will be best under similar circumstances as here described.

### **8.3 AMMONIA AFFECTS FROM MANURES**

Breakdown of organic nitrogen in composting may lead to a rapid release of ammonia and subsequent rise in pH and undesired ammonia volatilization. Since chicken manure is known to cause this problem from the large amount of organic nitrogen present, and since the project region showed large availabilities of this manure, the influence on composting was evaluated.

In Figure 8-6 we depict the amount of ammonia volatilized in composts up to 14 days of incubation of the test mixtures #1–#6 (see Table 8-2). There was little or no ammonia released where horse manure was the nitrogen source. However, where chicken manure is present the ammonia volatilization was large. Where straw was substituted for half the sawdust, there was more loss. The apple pomace significantly reduced ammonia release when compared with the others.

**Figure 8 - 6 Ammonia Loss Rate for Various UMDA Compost Blends Without Soil**

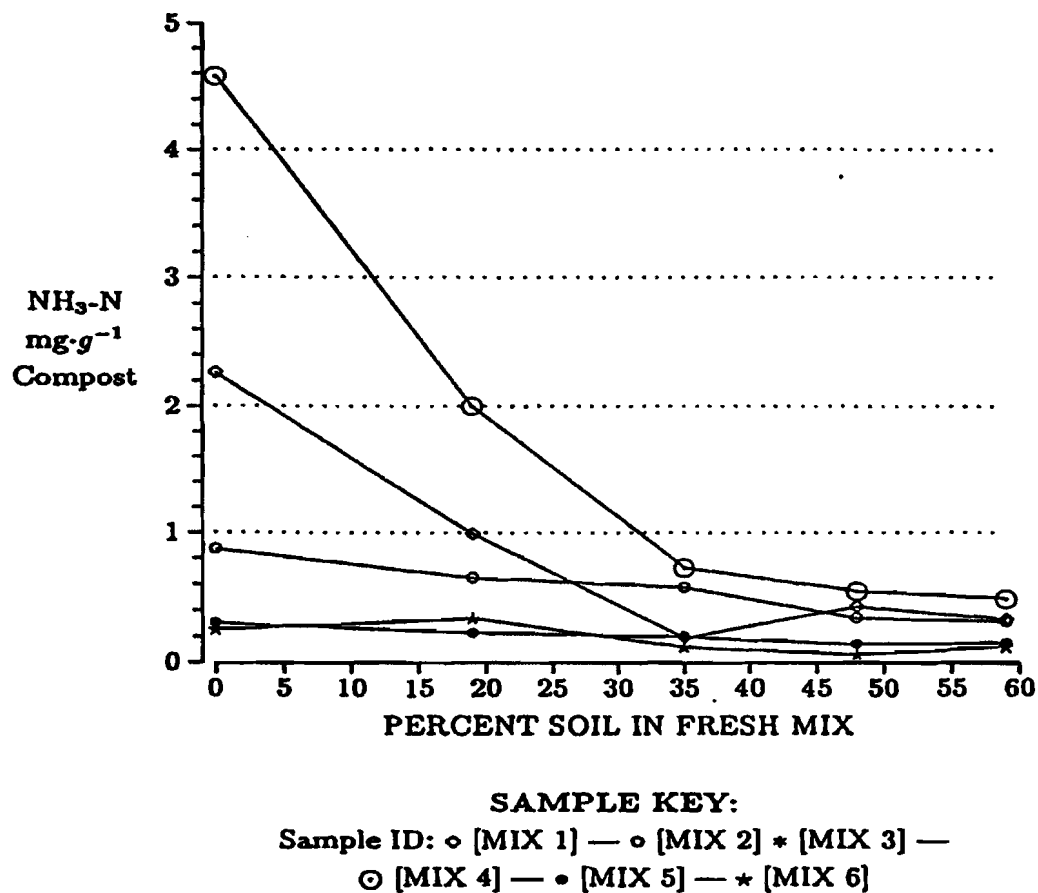


The quantity of ammonia which is lost can influence the apparent C:N ratio of the composts. A variable amount of total nitrogen was lost in the test composts, which decreased in the order MIX-4 > MIX-1 > MIX-2 > MIX-5 = MIX-6 > MIX-3. The range of total nitrogen lost for this series was 57%, 28%, 11%, 4%, 4%, <0.5%, respectively.

The loss of ammonia was significantly ameliorated by soil additions. The relationship is seen in Figure 8-7.

Based on data for the laboratory trials, it was recommended that chicken manure additions be limited for UMDA-soil composts. The maximum chicken manure used for the windrow trials was therefore 3-5% on a volume basis.

**Figure 8 - 7 Ammonia Loss Rate for Various UMDA Compost Blends in Relation to Soil Content**



## **SECTION 9**

### **BENCH-SCALE (ADIABATIC) TESTING OF RECIPES**

There is a need to test composting materials when new ingredients are to be incorporated into field demonstration trials (Sikora et al., 1983). In this study a laboratory screening model was developed to aid in selection of proper ingredients and a series of respiration trials to confirm rate of degradation.

#### **9.1 BENCH-SCALE DESIGN**

Laboratory analytical data may not provide adequate information alone on which to implement a composting program, particularly where source ingredient composition and availability change over time and where fluctuating rates of soil material are utilized. To conduct full scale pilots based on calculated mixtures of laboratory tested ingredients could result in costly errors and the risk that unsuccessful trial composts will have to be disposed of or re-treated.

Testing of compost ingredients and compost mixes with the respiration procedure is a satisfactory approach to evaluate composting. CO<sub>2</sub> respiration studies conducted for various ingredients may accurately predict degradation potential but they do not estimate performance and microbiological succession under various heating events found in composts.

Heating is an important parameter, but one which remains unknown in respiration trials normally conducted at static temperatures. In order to test composting heating potential prior to full scale implementation, bench scale tests are required. Therefore, Woods End developed and evaluated a test procedure to simulate compost heating.

The bench scale model for pre-testing ingredients developed in his study originated in previous research by USDA (Sikora et al., 1983). A portable bench scale unit was developed that would monitor and control a temperature differential of at least 0.1°C up to 6°C within a biological environment. Control mechanisms employed user supplied compressed air to cool and oxygenate the biological environment. In addition, control of a circulating bath heater is employed by means of sensing the temperature differential between the envelope of bath water and the pile chamber to assure the required heat environment.

The bench scale system dynamically insulates the test compost to simulate thermophilic temperature rise by limiting and controlling heat-loss in a real-time feed-back control mechanism. Theoretically, such as test device should help to eliminate compost mixtures which do not have the potential to induce enough calorific release to sufficiently heat a compost loaded with contaminated soil under optimal moisture and aeration conditions.

Woods End evaluated original plans of a prototype bench scale unit of the USDA (Sikora et al., 1983), and set objectives and stipulated functionality for a modern electronic design (C. B. Ives Company, 1991). A simplified schematic plan for the equipment is reproduced below (see Figures 9-1 and 9-2).

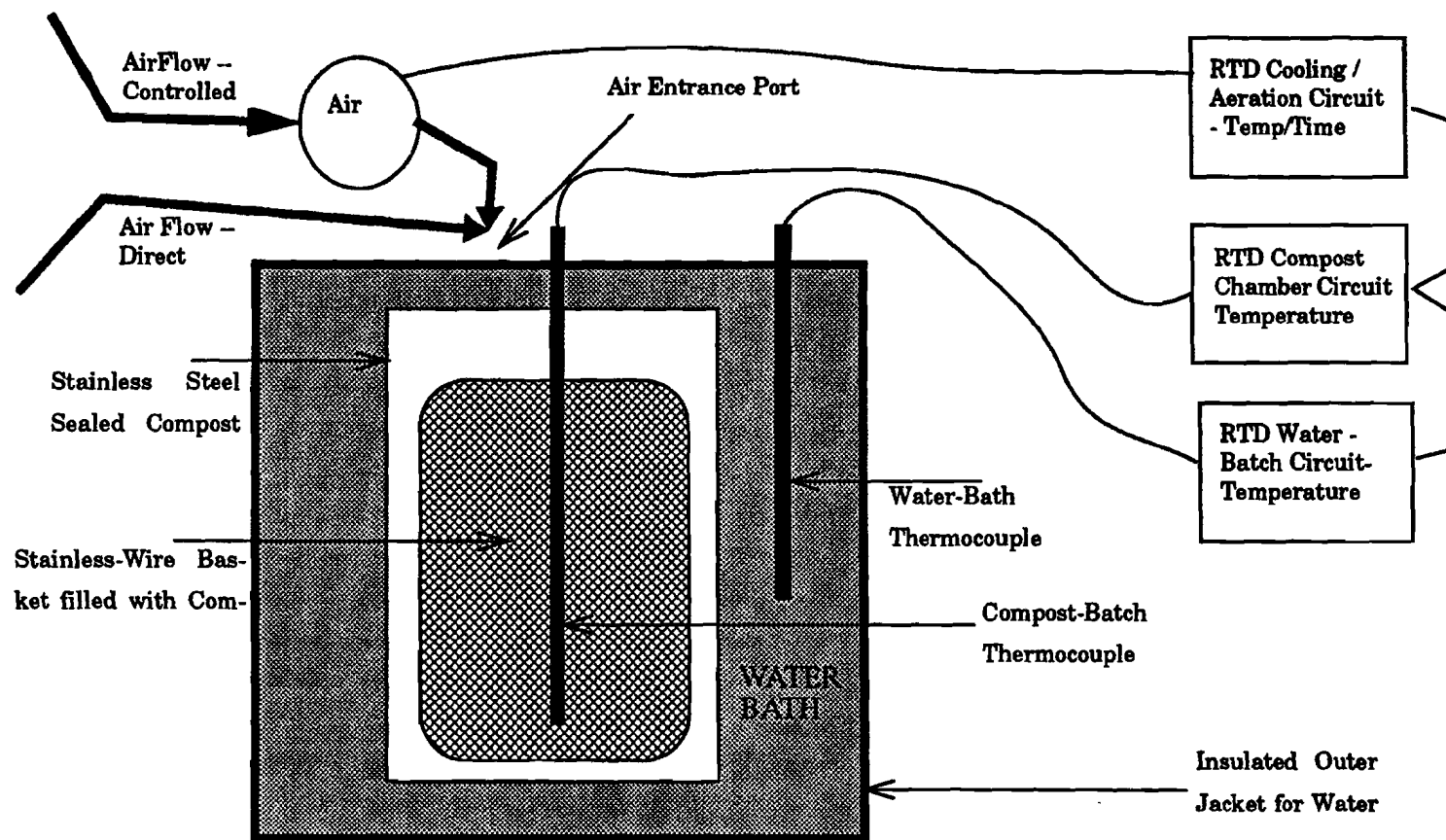
## **9.2 BENCH-SCALE UNIT TESTING**

Currently, there is no information which details the influence of soil loading on decrease in heat potential of contaminated soil composting (USATHMA, 1989; Woodward, 1990). The adiabatic units were used to evaluate the relative performance of pre-selected compost recipes using differing load rates of soil. By providing precisely the same ambient conditions, the adiabatic units provide an accurate measure of differences in heating arising from the material itself. Figure 9-3 presents the results of monitoring four-selected compost mixtures in the adiabatic units for 35 days.

The basic adiabatic model incorporates the following features:

- Bench Composter Electronic panel to operate and monitor the vessel;
- Stainless-steel sealed, vessel of 1 to 3-liter size
- Electronic control of water-bath with variable set-option to maintain at least a 1°C temperature differential between the water-bath mantel and the compost inside the vessel;
- Variable aeration control to set air flow at desired points;
- Optional monitoring ability for CO<sub>2</sub> and O<sub>2</sub> production and removal.

The data in Figure 9-3 indicate an impressive rise to high heat of composts with varying amounts of soil. There is an evident diminishing function as soil rate increases. In Table 9-1 the average temperatures recorded are calculated over 35 days of performance in relation to soil loading rate. There is no loss of performance with 10% soil, but a decline sets in at the 20–30% rates.

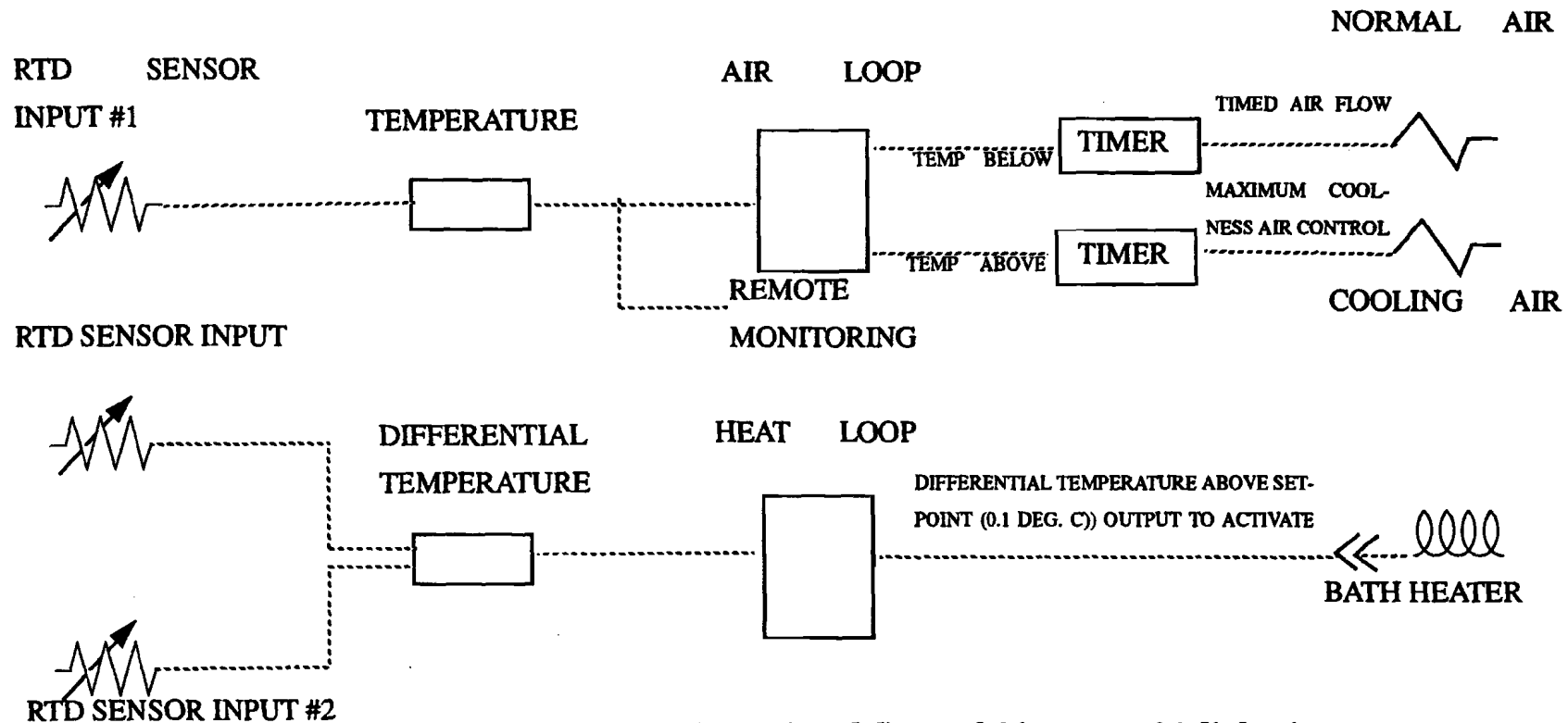


**Figure 9 - 1 Plan of Adiabatic Composter Unit Used by Woods End Research Laboratory to Test Compost Mixtures for Contaminated Soil Composting**



## UMDA Adiabatic Composter

### Functional Control Diagram



**Figure 9 - 2 Functional Control Diagram of Adiabatic Composter Unit Used by Woods End Research Laboratory to Test Compost Mixtures for Contaminated Soil Composting**

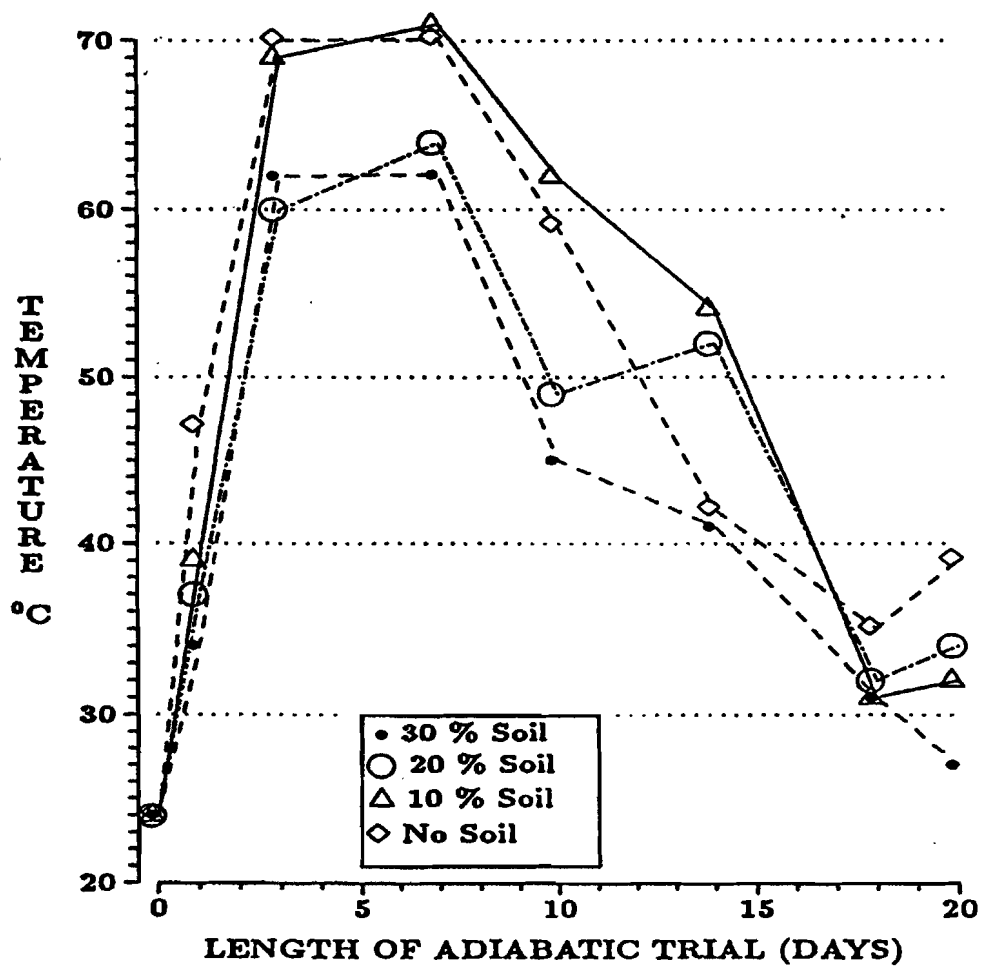
**Table 9-1 Soil-Loading Influence on Observed Heating in Adiabatic Composter Units**

<b>Treatment Type</b>	<b>Temperature Observed Avg C° 35 Days</b>
Control, Basic Compost Mix	49.7
+ 10% v/v Contaminated Soil	50.2
+ 20% v/v Contaminated Soil	47.8
+ 30% v/v Contaminated Soil	42.3

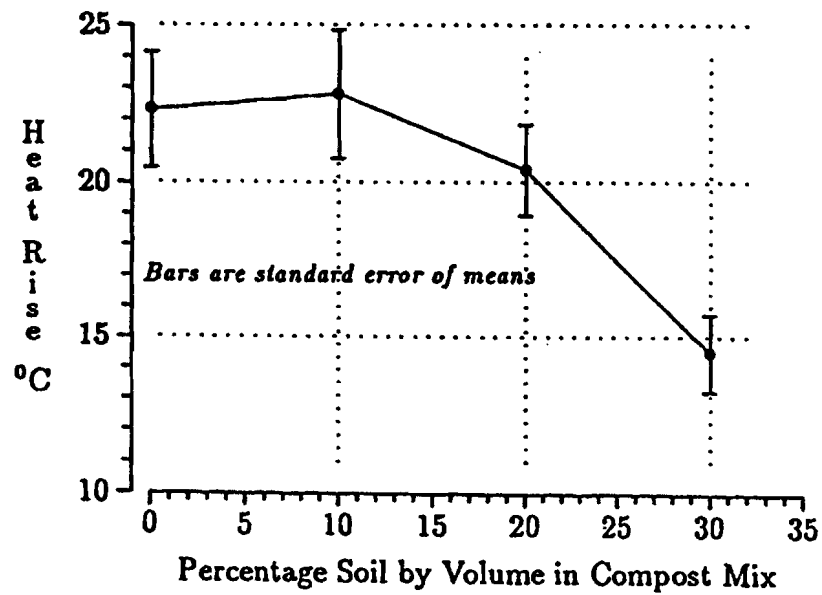
In Figure 9-4 the relative rise over ambient in laboratory trials with the adiabatic unit loaded at differing soil rates was plotted. The data show that soil inclusion results in a non-linear decrease in heating ability as the percent soil volume is increased.

Thus, if the line in Figure 9-4 is extended, it is estimated that an inclusion rate of 40% soil volume will result in an average temperature rise of only 10°C within 35 days. While the data from this trial is limited, it corroborates the other respiration trial results where the performance of several compost blends at soil loading up to 35% by volume were evaluated (see Figure 8-4). In the first UMDA trials, soil loading at 40% resulted in significantly less heating and contaminant degradation than lower volumes (Weston, 1991).

**Figure 9 - 3 Temperature Performance of Compost Pre-Mixes in Adiabatic Composter Units**



**Figure 9 - 4 Relationship of Soil Inclusion Rate in UMDA Compost and Average Temperature Above Ambient Attained Over 30 Days**





## SECTION 10

### COMPOST RECIPE FINALIZATION

The data from previous trials supports the notion that high loading rates of soil for composting may be achieved. Evidence exists that there is an increased efficiency of degradation with increased soil loading up to 25% by volume. Furthermore, there is no significant decline in heating potential until around 30% by volume soil.

The recommendations suggested from this research are predicated on the fact that a procedure to optimize respiratory potential of soil composts was adopted. Under other circumstances with other compost ingredients, it can not be predicted what efficiencies or temperatures can be achieved.

This study pre-selected several traits from which optimization of the mix recipe were determined. These traits include C:N ratio, moisture content and bulk density. Additionally, we refine the procedure to evaluate texture and porosity.

The actual procedure used to compute relative quantities of two or more ingredients is based on simultaneous equation solving (Brinton and Seekins, 1988). If we have two ingredients "A" and "B" which we intend to mix, and where  $C$  and  $N$  are carbon and nitrogen contents, respectively, then in order to find the relative mixing proportions for the (A) component and for the (B) component where  $C$  and  $N$  are targeted carbon and nitrogen (C:N) portions:

$$(i) (SampleA)_C = (SampleB)_C = C \quad (3)$$

$$(ii) (Sample A)_N + (SampleB)_N = N$$

The procedure is to solve first for  $(SampleB)$  by dividing each equation by its coefficient for  $(SampleA)$ , eliminate  $(SampleA)$  by subtracting  $(ii)$  from  $(i)$ , solving for  $(SampleB)$ , and then by substitution to arrive at  $(SampleA)$ .

The basic mixtures used in this project were computed by solving for 2 or 3 unknowns of 2 or 3 ingredients where C:N moisture and density were solved for. Other simple procedures using weighted averages have also been described (Rynck, 1992). The data collected for source ingredients as seen in Tables 7-6 and 7-7 permits extensive computations based on any attribute to be undertaken.

The recipe model and the predictive capabilities gave satisfactory results. In Table 10-1, the recipe and the prediction for two compost piles are given (Weston, 1993).

The data indicate predictability was good based on the recipe model used in the study. Organic content found was often lower than predicted; the respiration rate was high enough that between measuring fresh samples and mixing the recipes, some solids loss could have occurred.

**Table 10-1 Prediction from Recipe and Actual Observed Values for Day 0 UMDA Composts**

TRAPP	Recipe Value	CWR7 Found	CWR8 Found
Density, lb/ft <sup>3</sup>	52	53	53
Moisture, %	29.7	32.0	32.4
Organic Matter % as is	16.6	13.2	14.2
C:N Ratio	31.8	22.9	26.6
Total-Nitrogen % as is	0.276	0.284	0.286

We selected a C:N ratio of 32–40 as optimal for composting during the UMDA trials. This study does not evaluate the effect of varying ratios of carbon to nitrogen. Increasing carbon relative to nitrogen is known to cause longer, cooler composting processes. Theoretically, increased C:N should also cause greater carbon loss, since composts tend to stabilize at or around a C:N of 15–17 (Parnes, 1990).

The ideal amount of moisture used in composting can not be given without first knowing the water-holding capacity and the soil content. In this project, the required moisture was determined from the data presented in Table 7-10, as was also the bulk density percentage water holding capacity.

## SECTION 11

### COMPOST POROSITY FACTORS

Theoretically, compost mix formulas and composting conditions are likely to affect the porosity and hence resultant oxygen penetration of the compost piles. Field tests during the second phase of the UMDA study demonstrated that oxygen in the core of the unaerated windrow was measurably depleted shortly after turning (see Figure 11-1) (Weston, 1993). This suggested that the refresh rate of air may have been less than the consumption rate. The factors that influence the relationship are compost porosity and oxygen consumption rate. Since oxygen consumption is a positive factor which has been deliberately selected for in composting contaminated soil, it was felt to be important to focus on porosity which controls refresh rate.

A laboratory trial was established to determine the influence of pile size and turning conditions on the apparent porosity or pore-volume of the composts (see Figure 11-2). Porosity is defined as the amount of free air space not occupied by particles or water. Compost porosity is determined as follows (Page, 1982):

$$\% \text{ porosity} = 100\% - (\text{wet bulk density} / \text{particle density}) \times 100\% \quad (4)$$

The compost bulk density ( $\text{g} / \text{cc}^{-1}$  total volume) has been shown to change in proportion to increasing age and increased soil content. Furthermore, the compost particle density measured by the water displacement method (Page, 1982) increases with age and soil content. If particle density is not taken into account, then computations using the difference method (total volume less dry bulk density) (Page, 1982) tend to underestimate actual air volume.

The data in Figure 11-2 indicate that the air volume in static piles ranged from 65 to 52% and was significantly greater than the porosity for turned windrows which ranged from 50 to 27% at simulated depths. The reduction in porosity with depth into the pile results from the increase in compaction from overlying material and is influenced by the bulk density of the product. The depth is simulated in the laboratory by applying pressure equivalent to the bulk density.

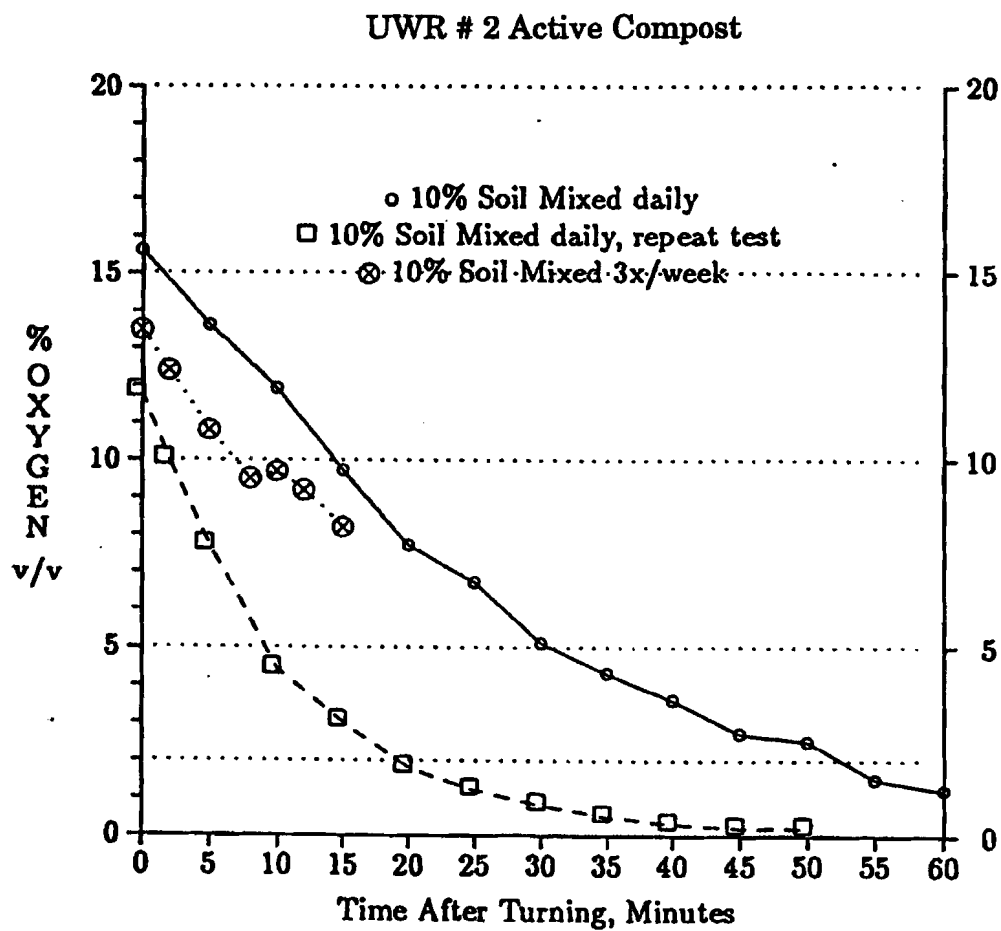
Reduction in compost air volume may adversely influence composting performance since it means that oxygen will become depleted more quickly. There is little information regarding optimal values for compost porosity. Values above 50% air space have



been recommended for active composts (Lechner, 1992). Windrow turning by high-speed mechanical agitation in this project may have acted to break-down texture-bearing materials and is likely to explain the lower porosity in the windrow samples. Since the oxygen readings seen in Figure 11-1 are taken near the core, the reduction in porosity observed with depth may be a contributing factor. Data collected in the second UMDA trial support that this porosity factor did not adversely affect explosives removal, since removals in windrows were better than or equal to those in static piles.

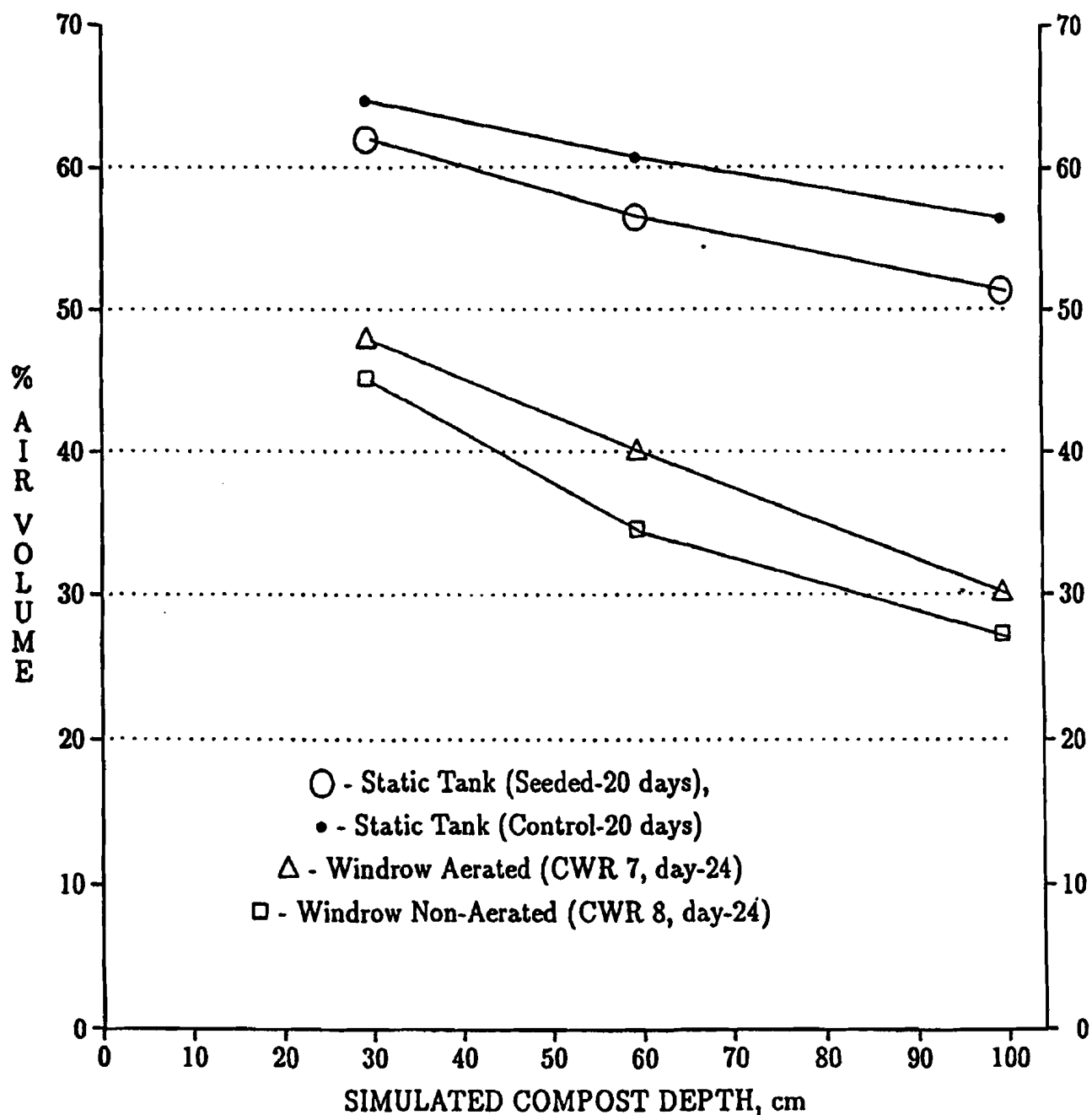
The effect of sample depth of daily turned windrows with and without added air was evaluated in a separate trial, seen in Figure 11-3. The data indicates that compost porosity from windrow systems is fairly uniformly low under all circumstances.

**Figure 11 - 1 Oxygen Content in Relationship to Time After Windrow Turning of Active Contaminated Soil Compost**

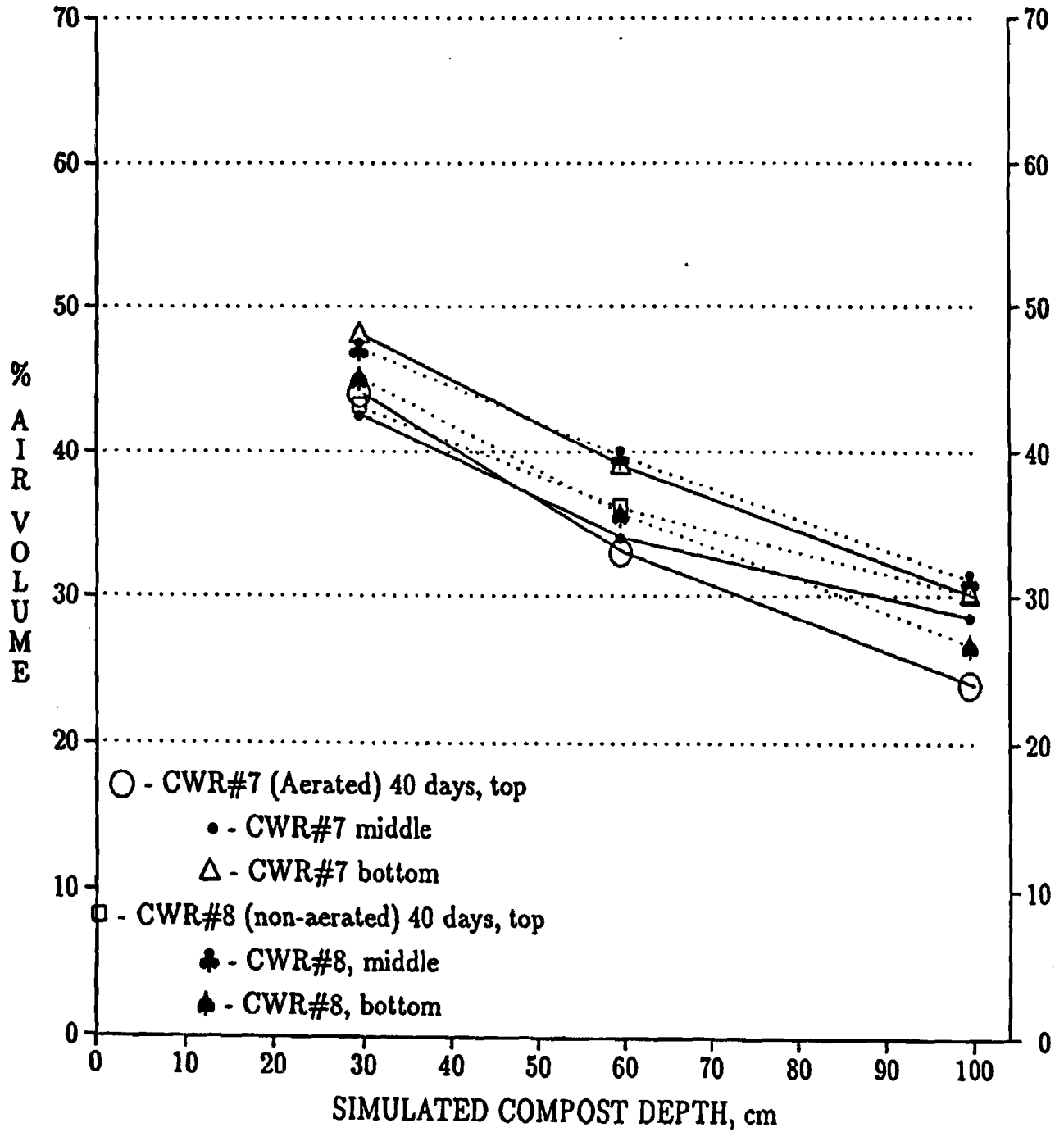


**Figure 11 - 2 Compost Air Volume as a Function of Simulated Pile Depth and Pile Management**

Reference WERL Lab # 2560.0 -.1 and 2573.0 -.1



**Figure 11 - 3 Compost Air Volume as a Function of Pile Management,  
Depth in Pile, at Simulated Depths**





## **SECTION 12**

### **COMPOST PROCESS MONITORING**

During a composting process, events such as heat rise and loss of moisture occur and form the basis for process monitoring. For example, heat may be used to trigger cooling fans or a turning cycle, and moisture loss may be gauged to prevent over-dryness from taking place.

The need to monitor the compost process is dictated by the fact that many compost events occur rapidly and are not easily predicted, but result in changes that may need to be quickly resolved. Moisture declines during high-heating and may need to be frequently supplemented. Volume or porosity is influenced by choice of ingredients and may require adjustment to maintain effective aeration. For example, an important indicator of process quality is the level of volatile organic acids (VOA), which are increased under conditions of low oxygen concentrations and rapid breakdown.

Woods End Laboratory provided information and testing for aspects of the UMDA monitoring plan. The important traits monitored during composting included but were not limited to the following (see Table 7-2):

- Moisture content;
- Pore Space
- Volatile organic acids
- Organic matter content
- pH, ammonia content
- Microbial levels

#### **12.1 INITIAL TEST WINDROWS**

Laboratory analyses were performed during the early phase of composting of the first UMDA test windrows (UWR1, UWR2), (Weston, 1992; Weston, 1993), containing 10% uncontaminated soil. UWR1 was turned 3 times per week and UWR2 every day. The relative performance of the process was evaluated in terms of composition (C:N, pH, ammonia) and presence of volatile organic acids, potentially produced during semi-anaerobic fermentation.

The data indicates that in the early phase (first week) of composting, the contents of respective organic acids in the two samples were (on a dry basis) 16,228 mg/kg (turned 3 time per week) as against 23,696 mg/kg for the daily turned piles. Five days later we re-tested the VOAs and found them to have dropped considerably to 10,182 mg/kg for UWR1 (turned 3 times per week) and 9,461 mg/kg for UWR2 (daily). It can not be explained why at first the more rapid turning resulted in higher VOAs; it may have been a recipe factor. The VOAs in these piles quickly dropped to similar levels after about the 10th day (see Figure 12-1).

The other traits such as moisture, pH and C:N were close to expected ranges, and the pH values started on the low side and increased as the VOAs came down. For example, the average pH in the lab on the first samples was 6.0 and 5 days later it was 8.0, an decrease of two orders of magnitude of hydrogen ion. In windrows UWR5 and UWR6 we monitored for respiration rate during composting. The rate declined more rapidly in the aerated pile, and both were very low and nearly identical at day 44 (see interpretation glossary in the Appendix).

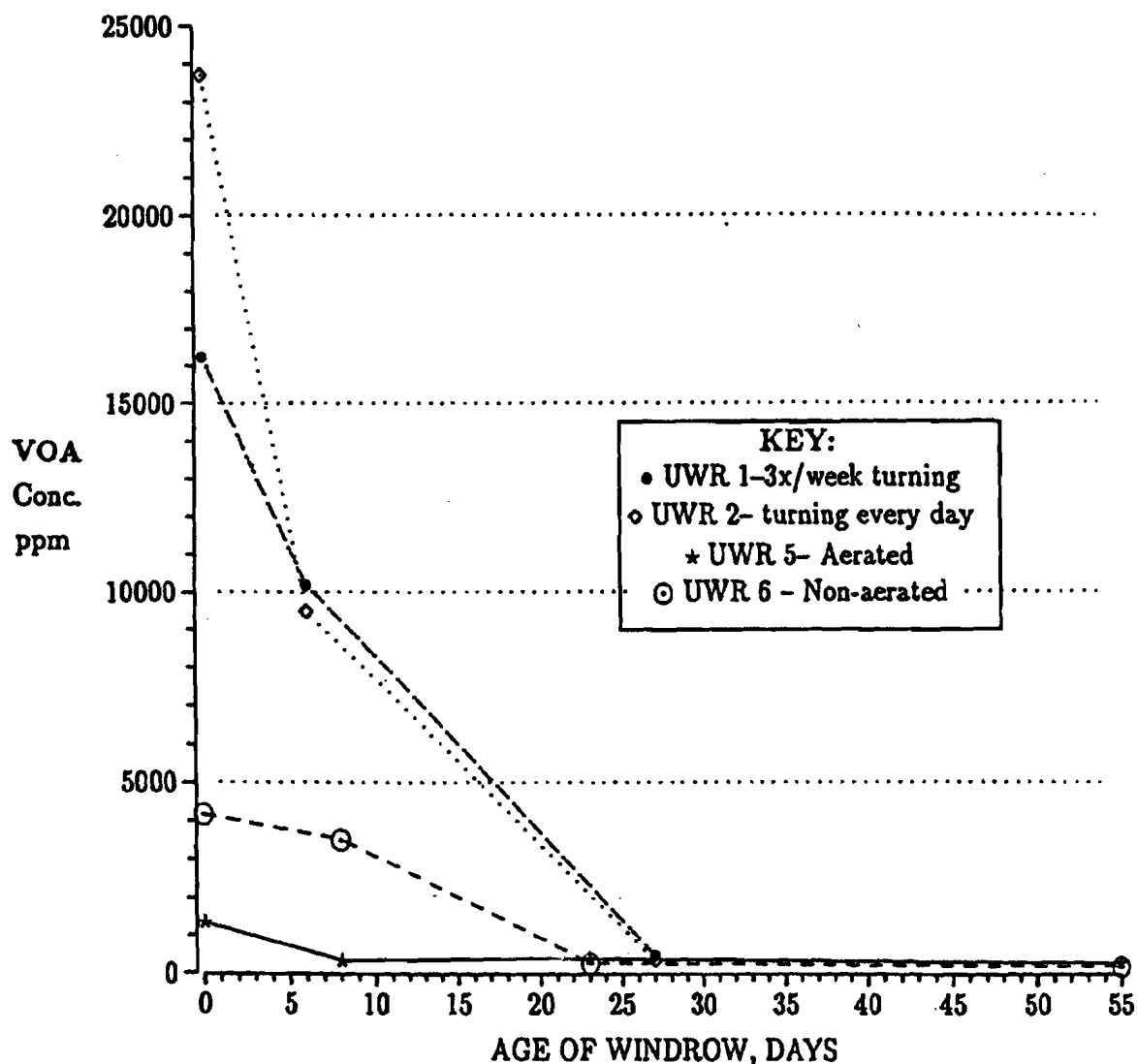
It is notable that almost one month later (day 27 sampling) the VOAs in Piles 1 & 2 had fallen to close to the minimum detectable level (MLD) of 300–600 mg/kg. Thus, if anaerobic conditions existed at one point, they did not have any lasting effect on VOAs. It is doubtful from this data if the compost process was adversely affected.

Microbiological tests were first initiated by Woods End during the Pile 5–6 sequence. These data are seen in Table 12-2.

The biochemical data indicate very high total bacterial counts for both types of piles at the outset, with rapid declines of activity during composting. There was no evidence of differences imposed by the aeration/non-aeration sequence that can be gathered from this data.

Enzyme activity was slightly higher for aerated than non-aerated piles. For example, urease was positive throughout the aerated composting, and hydrolase activity was elevated. Thermophilic hydrolase activity, however, showed no difference between the treatments. Both piles did show fermentative activity (production of VOA) at the beginning and end of the process. *E. coli* survived the composting process, which is not unusual (Droffner & Brinton, 1994).

**Figure 12 - 1 Volatile Organic Acid Concentration in Windrows at Different Ages**



The data in Figure 12-1 show the changes in volatile acids with age of composts for paired groups of 10% and 30% soil at similar dates. With the earlier composts, there was a very high level of VOA initially which declined rapidly with age, and showed no relationship to whether or not air was added. In the later windrow composts, the non-aerated showed more initial VOA which did not decrease to background levels until 23 days as versus 8 days with supplemental aeration.



**Table 12-1 Laboratory Results - Initial Test Windrows**

Lab-No	H <sub>2</sub> O	pH	OM	TK N	C:N	NH <sub>3</sub> <sup>+</sup> N	NO <sub>3</sub> <sup>-</sup> N	VOA	ORP	Salt	CO <sub>2</sub> -C
	---as is---			-----% of TS-----				ppm TS	mV	mmhos /cm	% of C <sub>T</sub>
<u>Windrow UWR 1- turned 3x/week, 10% soil</u>											
Day 3	51.2	6.06	45.90	0.96	25.8	0.000	0.000	16228	148	8.2	na
Day 9	41.3	7.80	34.65	0.75	25.0	0.000	0.000	10182	489	7.2	na
Day 30-a	42.3	8.80	27.89	0.65	23.2	0.124	0.000	624	301	6.2	na
Day 30-b	40.7	8.80	29.82	0.56	28.8	0.110	0.000	486	348	6.4	na
<u>Windrow UWR 2- turned daily, 10% soil</u>											
Day 3	49.0	5.98	49.51	1.15	23.3	0.000	0.000	23696	190	10.4	na
Day 9	35.3	8.25	29.89	0.78	20.6	0.000	0.000	9461	405	8.2	na
Day 30-a	37.7	8.90	22.16	0.58	20.7	0.096	0.000	347	343	7.1	na
Day 30-b	36.4	8.80	24.31	0.56	23.2	0.074	0.000	339	354	8.3	na
<u>Windrow UWR 3- turned 3x/week, 20% soil</u>											
Day 30-a	40.8	8.20	17.53	0.55	17.2	0.273	0.000	18242	320	8.6	na
Day 30-b	35.4	8.10	21.63	0.47	24.9	0.209	0.000	7696	304	9.7	na
<u>Windrow UWR 4- turned daily, 20% soil</u>											
Day 30-a	37.5	8.60	17.22	0.49	19.1	0.135	0.000	2993	331	7.0	na
Day 30-b	36.4	8.60	13.40	0.43	16.7	0.117	0.000	1698	366	6.6	na
<u>Windrow UWR 5- 30% soil, aerated, turned</u>											
Day 0	20.0	8.20	12.02	0.26	25.0	0.069	0.000	1349	308	3.7	3.15
Day 10	17.5	8.30	10.44	0.22	25.5	0.052	0.000	349	329	4.8	0.72
Day 20	28.3	8.00	13.72	0.23	32.8	0.029	0.008	402	49	3.8	0.55
Day 44	28.2	8.15	12.37	0.25	26.7	0.006	0.021	301	27	3.4	0.31

**Table 12-1 (Continued) Laboratory Results - Initial Test Windrows**

Lab-No	H <sub>2</sub> O	pH	OM	TK N	C:N	NH <sub>3</sub> <sup>-</sup> N	NO <sub>3</sub> <sup>-</sup> N	VOA	ORP	Salt	CO <sub>2</sub> -C
	as is				% of TS			ppm TS	mV	mmhos /cm	% of C <sub>t</sub>
<b>Windrow UWR 6- 30% soil, non-aerated, turned</b>											
Day 0	25.7	6.15	11.80	0.36	17.7	0.077	0.000	4168	184	5.6	3.89
Day 10	22.2	7.50	10.93	0.32	18.5	0.172	0.000	3518	229	7.7	3.32
Day 20	25.3	9.00	12.43	0.21	31.7	0.087	0.000	289	66	4.0	0.91
Day 44	27.1	7.94	17.49	0.22	43.3	0.003	0.015	197	9	3.9	0.21

(n/a) indicates not analyzed  
(a-b) replicate testing)

**Table 12-2 Microbiological Traits of Initial Aeration-Test Windrows**

Sample	H30 °C	H50 °C	Dh	H <sub>2</sub> S	F	Da	Ur	AER	AN	THER	FU	E.c (M)	E.c (D)	Cl
<u>Windrow 5 Aerated</u>														
Day 0	7	18	106	nd	+	nd	+	10 <sup>8</sup>	10 <sup>8</sup>	10 <sup>3</sup>	<10 <sup>2</sup>	<10 <sup>2</sup>	n/t	<10 <sup>2</sup>
Day 10	8	16	94	nd	nd	nd	+	10 <sup>4</sup>	10 <sup>3</sup>	10 <sup>2</sup>	<10 <sup>2</sup>	<10 <sup>2</sup>	neg	<10 <sup>2</sup>
Day 44	0	12	132	nd	+	nd	+	10 <sup>3</sup>	10 <sup>3</sup>	10 <sup>2</sup>	10 <sup>2</sup>	10 <sup>4</sup>	pos	10 <sup>2</sup>
<u>Windrow 6 Non Aerated</u>														
Day 0	4	21	49	nd	+	nd	nd	10 <sup>8</sup>	10 <sup>8</sup>	10 <sup>3</sup>	<10 <sup>2</sup>	<10 <sup>2</sup>	n/t	10 <sup>3</sup>
Day 10	1	10	98	nd	nd	nd	nd	10 <sup>3</sup>	10 <sup>3</sup>	10 <sup>2</sup>	<10 <sup>2</sup>	<10 <sup>2</sup>	neg	10 <sup>2</sup>
Day 44	4	16	51	nd	+	nd	+	10 <sup>3</sup>	10 <sup>3</sup>	10 <sup>2</sup>	10 <sup>2</sup>	10 <sup>4</sup>	pos	<10 <sup>2</sup>

**Symbol Index to Microbiological tables**

+ ..... Denotes positive presence of organism, or trait measured  
 nd ..... Denotes no organism present or no activity for trait measured.  
 pos ..... positive DNA result  
 neg ..... negative DNA result  
 n/t ..... not tested for

**Acronym Index**

Dh ..... Dehydrogenase enzyme (reductive odor activity)  
 H(30°C) ..... Hydrolase Activity at 30°C  
 H(50°C) ..... Hydrolase Activity at 50°C  
 Da ..... Deaminase Activity  
 Ur ..... Urease Activity  
 THER ..... Thermophilic bacteria Count  
 FU ..... Fungal Count  
 H<sub>2</sub>S ..... Hydrogen Sulfide Production  
 F ..... Fermentation (VOA) production  
 AER ..... Aerobic Bacteria Count  
 AN ..... Anaerobic (facultative + obligative) Bacteria Count  
 E.c(M) ..... Escherichia.coli MUG test  
 E.c(D) ..... Escherichia.coli DNA test  
 Cl ..... Clostridia

## 12.2 STATIC SEED TANK MONITORING

The static vessel seed study was undertaken to ascertain influences on contaminant degradation of compost recycle. The following table gives a breakdown of the various samples obtained by Woods End for material evaluation. We have grouped the data by type of tank; first analyzing the differences in the day 1 tanks, all the initial tanks

at sequences of 20 days, and finally the day-20 samples from each of the control and seeded tanks.

The static seed data indicate several important points:

- Several traits and especially organic matter content varied more between batches than between treatments— i.e. the successive mixes of the same recipe introduced a large variation;
- All initial blends were very high in VOA content and low in respiration rate.
- VOA and respiration rate decline with age; however, C:N increases as a apparent result of net loss of nitrogen (pH was high);
- Each control/seed pair of sample data are more similar to each other than to any other sample.

**Table 12-3 Laboratory Results of Monitoring Static Compost Vessels**

Lab-No	H <sub>2</sub> O	pH	OM	TKN	C:N	NH <sub>3</sub> -N	NO <sub>3</sub> -N	VOA	ORP	Salt	CO <sub>2</sub> -C
---- as is----		-----% of TS-----						ppm TS	mv	mmhos /cm	% of C <sub>t</sub>
Initial control tanks											
Day 0-a†	57.2	5.55	37.07	0.89	22.4	—	—	12627	90	7.0	0.15
Day 0-b	56.9	5.50	38.42	0.91	22.8	—	—	13201	87	7.2	0.15
Day 0-c	58.0	5.50	37.48	0.87	23.4	—	—	13534	86	7.3	0.15
Day 20	49.3	6.35	30.79	1.00	16.7	0.157	0.007	6818	79	5.7	2.24
Day 40	47.5	7.10	42.49	0.86	26.8	0.104	0.011	4386	92	5.4	0.58
Day 60	54.1	6.10	43.89	0.96	24.6	0.096	0.007	10832	38	6.6	0.39
Initial seeded tanks											
Day 0	52.2	5.45	27.79	0.84	17.8	—	—	14006	140	8.4	0.34
Day 20	46.5	6.45	25.56	1.04	13.2	0.168	0.006	9827	94	6.7	2.27
Day 40	50.6	6.30	39.16	0.97	21.7	0.101	0.012	9040	36	6.1	0.54
Day 60	52.3	5.17	42.83	0.98	23.7	0.079	0.006	12367	32	7.2	0.09

**Table 12-3 (Continued) Laboratory Results of Monitoring Static Compost Vessels**

Lab-No	H <sub>2</sub> O	pH	OM	TKN	C:N	NH <sub>3</sub> -N	NO <sub>3</sub> -N	VOA	ORP	Salt	CO <sub>2</sub> -C
	as is				% of TS			ppm TS	mv	mmhos/cm	% of C <sub>t</sub>
20-day sample tanks (s = seeded)											
Day 20/ 20†	38.5	7.70	26.26	0.96	14.8	0.203	<0.001	5969	153	6.7	3.15
Day 20/ 20s	39.2	7.60	27.70	1.00	15.0	0.227	<0.001	7106	97	7.1	2.98
Day 40/ 20	33.6	8.80	45.73	0.84	29.3	0.128	0.003	1085	174	6.0	0.54
Day 40/ 20s	27.1	8.60	48.82	0.94	28.2	0.066	0.004	692	214	5.6	0.50
Day 60/ 20	47.9	9.06	43.86	0.72	32.9	0.073	0.000	414	206	4.4	0.82
Day 60/ 20s	41.4	9.11	40.49	0.81	27.1	0.055	0.003	491	194	4.5	0.42
Day 80/ 20	40.7	9.09	42.19	0.66	34.8	0.043	0.001	486	273	4.0	0.45
Day 80/ 20s	47.0	9.11	45.00	0.78	31.1	0.062	0.001	543	318	3.6	0.59

† indicates replicate testing (a, b, c) to verify uniformity.

(-) indicates not analyzed

Initial seeded tanks are at the start of each batch;

Sequence tanks are taken at 20 days after start-up of each successive batch and are either control (no seed) or (s) = seeded.

The microbiological data was collected only on some of the samples. The following points are highlighted:

- There were more microbiological differences imposed as a result of batches over time (Day 0 blends made at Day 0,20,60) than as a result of treatments (with and without recycle);
- The very first control mixtures showed unusually low microbiological properties (low bacterial counts) compared to later— this is most likely a recipe dependent factor;

- Anaerobic *Clostridium* was present in initial tanks but disappeared later;
- At 20 days, the pair (control/seed) were nearly identical, but the seeded had slightly higher enzyme activity which means more bacterial activity;
- at 60 days, the pair indicate the control has higher bacterial counts and activity than the seed.

### **12.3 FINAL CONTAMINATED WINDROW MONITORING**

The contaminated windrows were evaluated based on periodic sampling of top, middle and bottom profile composts. The sample description is seen in the following list.

The data shows a progression of increasing pH and declining VOAs during the composting, with little or no differentiation evident from sampling the profile at various depths. The pH increased more rapidly in the windrows than in the static tanks. Respiration rates were higher in the initial windrows than in the static tanks. This is also supported by the microbiological data which shows no measurable difference between the profiles.

There is little evident difference between the piles with regard to aerobic qualities. Pile 8 which did not have supplemental air, showed higher VOA and lower pH at the outset, but this would appear to an artifact of pile mixing rather than an actual difference on Day 1 of the aeration change. Final VOA content was higher in the non-aerated sample at 691 ppm average as compared to 516 in the aerated pile; the difference is not significant. Pile 7 showed slightly higher respiration and redox activity, and lost more organic matter than pile 8. The total aerobic and anaerobic organism counts fell by several orders of magnitude from the start to the end (Day 44) of the composts.

Microbiologically, Pile 8 gave more *Clostridium* at the outset; this appears to be related to the higher VOA and lower pHs. At the end, pile 7 gave slightly higher *Clostridium* counts. However, the levels are low.

**Table 12-4 Microbiological Traits of Static Vessel Seed Study**

Sample	Microbiological and Bio-Chemical Indicators													
	H30 °C	H50 °C	Dh	H <sub>2</sub> S	F	Da	Ur	AER	AN	THER	FU	E.c (M)	E.c (D)	Cl
<u>Initial Control Tanks</u>														
Day 0-a	3	9	0	nd	nd	nd	+	10 <sup>3</sup>	10 <sup>3</sup>	10 <sup>5</sup>	10 <sup>2</sup>	<10 <sup>2</sup>	neg	10 <sup>3</sup>
Day 0-b	3	8	0	nd	nd	nd	+	10 <sup>3</sup>	10 <sup>3</sup>	10 <sup>5</sup>	10 <sup>2</sup>	<10 <sup>2</sup>	neg	10 <sup>3</sup>
Day 0-c	3	5	0	nd	nd	nd	+	10 <sup>3</sup>	10 <sup>3</sup>	10 <sup>4</sup>	10 <sup>2</sup>	<10 <sup>2</sup>	neg	10 <sup>3</sup>
Day 20	10	19	156	nd	+	nd	+	10 <sup>8</sup>	10 <sup>8</sup>	10 <sup>2</sup>	10 <sup>6</sup>	<10 <sup>2</sup>	n/t	10 <sup>3</sup>
Day 60	0	29	177	nd	nd	nd	+	10 <sup>3</sup>	10 <sup>3</sup>	10 <sup>5</sup>	<10 <sup>2</sup>	10 <sup>4</sup>	pos	10 <sup>2</sup>
<u>Initial Seeded Tanks</u>														
Day 0	2	5	0	nd	nd	nd	+	10 <sup>4</sup>	10 <sup>4</sup>	10 <sup>6</sup>	10 <sup>2</sup>	<10 <sup>2</sup>	neg	10 <sup>3</sup>
Day 20	11	6	30	+	+	nd	+	10 <sup>8</sup>	10 <sup>8</sup>	10 <sup>3</sup>	10 <sup>6</sup>	<10 <sup>2</sup>	n/t	10 <sup>3</sup>
Day 60	0	17	285	nd	nd	nd	+	10 <sup>3</sup>	10 <sup>3</sup>	10 <sup>2</sup>	10 <sup>2</sup>	10 <sup>4</sup>	pos	10 <sup>2</sup>
<u>Twenty Day Sequence Sample Tanks</u>														
20/20	9	12	92	nd	+	nd	+	10 <sup>8</sup>	10 <sup>8</sup>	10 <sup>5</sup>	10 <sup>2</sup>	<10 <sup>2</sup>	n/t	<10 <sup>2</sup>
20/20s	19	4	190	+	+	nd	+	10 <sup>8</sup>	10 <sup>8</sup>	10 <sup>3</sup>	10 <sup>3</sup>	<10 <sup>2</sup>	n/t	<10 <sup>2</sup>
60/20	6	47	168	+	+	+	+	10 <sup>8</sup>	10 <sup>8</sup>	10 <sup>3</sup>	<10 <sup>2</sup>	10 <sup>3</sup>	neg	<10 <sup>2</sup>
60/20s	10	38	103	+	nd	nd	+	10 <sup>5</sup>	10 <sup>5</sup>	10 <sup>3</sup>	<10 <sup>2</sup>	10 <sup>4</sup>	pos	10 <sup>2</sup>

for key, see Table 12 - 2

**Table 12-5 Laboratory Monitoring Results - Final Composts**

ID LabNo	H2O	pH	OM	TKN	C:N	NH3- N	NO3-N	VOA	ORP x	Salt	CO2- C
	as is				% of TS			ppm TS		as is	% TS
<u>Windrow #7-AERATED PILES: Day 0</u>											
top	28.7	5.61	17.66	0.37	26.1	0.035	0.002	3029	91	5.4	1.61
middle	36.2	5.34	24.13	0.42	30.9	0.027	0.004	4060	101	4.0	1.17
bottom	31.2	5.06	17.04	0.47	19.7	0.050	0.004	6381	88	6.3	1.23
<u>Windrow #7- Day 24</u>											
mix	30.4	9.15	14.36	0.43	18.0	0.067	0.001	310	260	3.1	0.66
<u>Windrow #7- Day 40</u>											
top	30.4	7.07	12.62	0.36	19.1	0.011	0.004	621	166	4.4	0.45
middle	29.8	7.32	15.63	0.36	23.6	0.009	0.004	411	150	4.7	0.36
bottom	30.1	7.46	16.51	0.36	24.6	0.008	0.004	515	143	3.8	0.34
<u>Windrow #8-Non-AERATED: Day 0</u>											
top	34.0	5.03	21.90	0.43	27.5	0.051	0.001	10794	135	6.7	0.43
middle	29.9	4.95	19.89	0.42	25.8	0.034	0.001	4725	69	6.3	0.19
bottom	33.4	5.05	21.41	0.42	27.3	0.054	0.002	4647	88	7.1	1.32
<u>Windrow #8- Day 24</u>											
mix	33.7	9.15	18.95	0.46	22.1	0.113	0.000	434	317	4.9	0.90
<u>Windrow #8- Day 40</u>											
top	29.9	7.35	18.83	0.34	30.2	0.009	0.001	617	125	4.2	0.30
middle	30.7	7.44	16.61	0.33	27.0	0.014	0.001	727	86	4.0	0.34
bottom	31.0	7.40	16.59	0.33	26.8	0.010	0.001	730	77	.9	0.34



**Table 12-6 Microbiological Traits of Final Windrows**

Sample	H3O °C	H50 °C	Dh	H <sub>2</sub> S	F	Da	Ur	AER	AN	THER	FU	E.c (M)	E.c (D)	Cl
<u>Windrow 7</u>														
2551.0	1	6	33	+	+	-	+	10 <sup>9</sup>	10 <sup>9</sup>	10 <sup>2</sup>	10 <sup>5</sup>	10 <sup>3</sup>	n/t	10 <sup>2</sup>
2551.1	n/t	4	61	+	+	-	+	10 <sup>9</sup>	10 <sup>9</sup>	10 <sup>2</sup>	10 <sup>5</sup>	10 <sup>3</sup>	n/t	10 <sup>2</sup>
2551.2	2	3	41	-	+	-	+	10 <sup>9</sup>	10 <sup>9</sup>	10 <sup>2</sup>	10 <sup>5</sup>	10 <sup>3</sup>	n/t	10 <sup>2</sup>
2587.0	2	34	43	-	+	-	+	10 <sup>6</sup>	10 <sup>6</sup>	10 <sup>7</sup>	10 <sup>2</sup>	10 <sup>4</sup>	pos	10 <sup>3</sup>
2587.1	2	15	49	-	+	-	+	10 <sup>6</sup>	10 <sup>7</sup>	10 <sup>6</sup>	10 <sup>2</sup>	10 <sup>4</sup>	pos	10 <sup>3</sup>
2587.2	1	40	49	-	+	-	+	10 <sup>6</sup>	10 <sup>7</sup>	10 <sup>7</sup>	10 <sup>3</sup>	10 <sup>4</sup>	n/t	10 <sup>3</sup>
<u>Windrow 8</u>														
2551.3	n/t	2	45	+	+	-	-	10 <sup>9</sup>	10 <sup>8</sup>	10 <sup>2</sup>	10 <sup>5</sup>	10 <sup>3</sup>	n/t	10 <sup>3</sup>
2551.4	n/t	3	18	-	+	-	-	10 <sup>5</sup>	10 <sup>6</sup>	10 <sup>2</sup>	10 <sup>5</sup>	10 <sup>3</sup>	n/t	10 <sup>3</sup>
2551.5	3	5	29	-	+	-	+	10 <sup>7</sup>	10 <sup>7</sup>	10 <sup>2</sup>	10 <sup>2</sup>	10 <sup>3</sup>	n/t	10 <sup>3</sup>
2587.3	n/t	15	49	-	+	-	-	10 <sup>6</sup>	10 <sup>6</sup>	10 <sup>7</sup>	<10 <sub>2</sub>	10 <sup>4</sup>	pos	10 <sup>2</sup>
2587.4	1	15	34	+	+	-	-	10 <sup>6</sup>	10 <sup>7</sup>	10 <sup>7</sup>	<10 <sub>2</sub>	10 <sup>4</sup>	pos	10 <sup>2</sup>
2587.5	1	12	39	-	-	-	-	10 <sup>6</sup>	10 <sup>6</sup>	10 <sup>7</sup>	10 <sup>2</sup>	10 <sup>3</sup>	n/t	10 <sup>3</sup>

n/t = not tested; for key to symbols, see Table 12-2.

---

## **SECTION 13**

### **RECOMMENDATIONS**

#### **13.1 PRE-TESTING INGREDIENTS**

Pre-testing of compost ingredients is an important pre-requisite to composting as it provides a means to assess the key traits which are important in recipe development. It is not possible to provide target values for source materials themselves. Rather, the physical and chemical traits are significant only in their bearing on the qualities of the initial compost mix. The target composition of the initial compost mixes is indicated in Table 13-1

**Table 13-1 Target Active Compost Monitoring Traits**

<b>Trait</b>	<b>Target</b>
C:N Ratio	30-40
Moisture	60-80% of WHC
Density	700-1200 lb / yd <sup>3</sup>
Porosity	>60%
VOA Content	< 15000 ppm
CO <sub>2</sub> Rate	> 1.0%C / day <sup>-1</sup>

#### **13.2 COMPOST INGREDIENT HANDLING**

Compost ingredients are best handled and measured on a bulk weight basis. Conversions back and forth to volume basis are at best confusing and should be performed only when needed. It is desirable to have a weigh scale on site to measure quantities as an alternative to guessing at mix recipes from variable volume data alone.

### **13.3 COMPOST PROCESS MANAGEMENT**

Active composts should be monitored on a weekly basis for traits which are important to bring about control and successful outcome of the process. The physical, chemical and biological traits for monitoring active compost include those listed in Table 13-2. A guidance for interpretation of these and other parameters is given in the appendix (see Interpretation Sheet- Appendix A).

**Table 13-2 Target Active Compost Monitoring Traits**

<b>Trait</b>	<b>Target</b>
Moisture	60-80% of WHC
Porosity	>30%
VOA Content	< 2000 ppm
Aerobic Bacteria	>10 <sup>6</sup> cfu/g
Obligate Anaerobes	<10 <sup>3</sup> cfu/g

## **SECTION 14**

### **REFERENCES**

- ANL (1992) Evaluation of the Feasibility of Biodegrading Explosives-Contaminated Soils and Groundwater at the Newport Army Ammunition Plant (NAAP). Report# CETHA-TS-CR-92000. U.S. Army Toxic and Hazardous Materials Agency. Prepared by: Argonne National Laboratory , Argonne Il.
- G. Berg (1983) Viral Pollution of the Environment. CRC Press, Boca Raton, Fl
- Balows, A. *et. al.* (1991) Manual of Clinical Microbiology. 5th Edition. Amer. Soc. Microbiol. Wash DC
- United States EPA (1980) Manual for Composting Sewage Sludge by the Beltsville Aerated-Pile Method. EPA-600/8-80-022
- Bongiovanni, R. *et al* (1984) Analysis of trace amounts of six selected poly-nitro compounds in soils. Am. Ind. Hyg. Assoc J. Vol. 45-4:222-226 from U.S. Army Environ. Hyg. Agency, Aberdeen Proving Grounds, MD.
- Boopathy, R. *et al* (1993) Anaerobic Removal of 2,4,6-trinitrotoluene (TNT) under different electron accepting conditions: laboratory study. Water Env. Res. 65:271-275
- Brinton, W.F. & Droffner, M.W. (1994) Microbial Approaches to Characterization of Composting Processes. Compost Science Vol. 1:3
- Brinton, W.F.c & Seekins, M.D. (1988) Composting Fish By-products: A Feasibility Study. Time & Tide Resource Conservation and Development, Waldoboro, ME
- Cabelli, G.J. (1977) Clostridium perfringens as a water quality indicator. in: Bacterial Indicators/Health Hazards Associated with waste water. American Society for Testing and Materials, ASTM, Philadelphia, PA
- Casida Jr., IE (1964) Soil Dehydrogeanse Activity. Penn State University Press. State College PA
- CH2M Hill (1992) Feasibility Study for the Explosives Washout Lagoons (Site 4) Soils Operable Unit Umatilla Depot Activity (UMDA) Hermiston, Oregon. Report# CETHA-BC-CR-92017. U.S. Army Toxic and Hazardous Materials Agency. Prepared by: CH2M Hill and Morrison Knudsen Environmental Services, Bellevue, Washington.

- Curiale, M.S., et. al. (1990) Colorimetric Deoxyribonucleic Acid Hybridization Assay for Rapid Screening of Salmonella in Foods: Collaborative Study. J. Assoc, Anal. Chem. 73: 248-256.
- Dames & Moore (1992) Risk Assessment for the Explosive Washout Lagoons (Site 4) Umatilla Depot Activity Hermiston Oregon. Report# CETHA-BC-CR-92014. U.S. Army Toxic and Hazardous Materials Agency. Prepared by: Dames & Moore, Bethesda, Maryland 20814.
- Darland, G & Davis, BR (1973) U.S. Dept. Health, Education and Welfare, Public Health Service. CDC Report Sept., 1973
- Doyle, R., et. al. (1982) Treatment of TNT And RDX Contaminated Soils By Composting. Atlantic Research Corporation EPA/et al Management Of Uncontrolled Hazardous Waste Sites Natl. Symposium, DC, Nov 29-Dec 1, 82, P209 (5)
- Doyle, R., et. al. (1986) Composting Explosives/Organics Contaminated Soils. Report# AMXTH-TE-CR-86077 Atlantic Research Corporation report to U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Grounds, Maryland
- Droffner M.L. & Brinton, W.F. (1994) Evidence for the Prominence of Different Well Characterized Gram Negative Mesophilic Bacteria in the Thermophilic Environment of Composts. American Society of Microbiology, Abstracts for the Annual Meeting. Q-266.
- Farmer, JJ (1985) Jrnl. Clin. Microbiol. 21:46-76
- Fernando, T and A. Steven (1990) Biodegradation Of Munition Waste, TNT (2,4,6-Trinitrotoluene), And RDX (Hexahydro-1,3,5-Trinitro-1,3,5-Triazine) by *Phanerochaete Chrysosporium*. Emerging Technologies In Hazardous Waste Management II Symposium, Atlantic City, NJ, JUN 4-7, 90, P214(19)
- Greenberg, A.E. et. al.(1992) Standard Methods for the Examination of Water & Wastewater 18th Edition. American Water Environment Federation. Hannover, Md.
- Hajna and Perry (1943) American Journal of Public Health. 33: 550
- Horwitz, W. Editor (1992) Official Methods of Analysis. 27 Edition. Association of Official Analytical Chemists. Arlington VA

- Isbister, J.D. et.al. (1982) Engineering and development support of general decon technology for the U.S. Army's installation restoration program. Task 11. Composting of explosives. Atlantic Res. Corp., Alexandria, VA, USA
- C.B. Ives Company (1991) Bench-Scale Composting Unit Manual. Prepared for Woods End Research Laboratory. internal document
- Jue C.K. and Lipkje, PN (1985) Determination of reducing sugars in the nanomole range with tetrazolium blue. *Jrn. Biochem. Phys. Methods.* 11:109-115
- Lechner, P. (1992) Neue Untersuchungsergebnisse zur Optimierung von Kompostierungsprozessen [New Investigations for Optimizing Compost Processes] Institut am Mikrobiologie. BAKU Institute, University of Vienna, Austria
- Arthur D. Little (1987) Testing to Determine the Relationship Between Explosive Contaminated Sludge Components and Reactivity (Task Order Number 1) Report# AMXTH-TE-CR-86096. U.S. Army Toxic and Hazardous Materials Agency.
- Arthur D. Little (1987) Engineering/Cost Evaluation of Options for Removal/Disposal of NC Fines (Task Order Number 3/Subtask 3.5) Report# AMXTH-TE-CR-87134. Final Report to: U.S. Army Toxic and Hazardous Materials Agency.
- McFarland M. J. et. al. (1989) Biological Composting Of Petroleum Waste Organics Using The White Rot Fungus *Phanerochaete Chrysosporium*. IGT GAS OIL COAL & ENV BIOTECHNOLOGY 2nd Intl. Sym, New Orleans, LA, Dec 11-13, 89, P37(21)
- Moat, A.G. (1979) Microbial Physiology. John Wiley & Sons, Inc.
- MKES (1992) Explosives Washout Lagoons Soil Operable Unit Supplemental Investigation Technical and Environmental Management Support of Installation Restoration Technology Development Program Umatilla Depot Activity Hermiston, Oregon Report# CETHA-BC-CR-92016. U.S. Army Toxic and Hazardous Materials Agency. Prepared by: Morrison Knudsen Environmental Services and CH2M Hill.
- Noss, C.I. and Chyrek, R.H. (1983-4) Tertiary treatment of effluent from Holston AAP (Army Ammunition Plant) industrial liquid waste treatment facility. Part 3&4. Ultraviolet radiation and hydrogen peroxide studies: TNT, RDX, HMX, TAX, and SEX. Army Med. Bioeng. Res. and Dev. Lab., Fort Detrick, MD, USA
- ORNL (1990) Characterization of Explosives Processing Waste Decomposition Due to Composting. Report# DOE IAG 106-B123-A1. U.S. Army Medical Research and De-

- velopment Command. Prepared by: Oak Ridge National Laboratory , Oak Ridge, Tennessee.
- Workshop on Composting of Explosives Contaminated Soils U.S. Army Toxic and Hazardous Materials Agency. (1989) Report# CETHA-TS-SR-89276.
- ORNL (1991) Characterization of Explosives Processing Waste Decomposition Due to Composting Final Phase II Report. Report# DOE IAG 106-B123-A1. U.S. Army Medical Research and Development Command. Prepared by: Oak Ridge National Laboratory, Oak Ridge, Tennessee.
- Oregon Dept. Agriculture (1989) Oregon Agriculture. Extension Publication, Corvallis Oregon.
- Page, A.L. (1982) *Ed. Methods of Soil Analysis-Part 1&2*, Amer. Soc. Agronomy, Madison WI
- Parnes, R. (1990) *Fertile Soil*. Ag. Access, Davis, Ca
- Qiu Xiujin and McFarland, M. (1991) Bound Residue Formation at PAH Contaminated Soil Composting Using *Phanerochaete Chrysosporium*. Hazardous Waste & Hazardous Materials, Spring 91, v8, n2, p115 (12)
- Rajat, G. et.al. (1991) Treatment of Explosives Contaminated Lagoon Sludge. Hazardous Waste & Hazardous Materials, Fall 91, v8, n4, p319 (21)
- ReTec (1990) Final Report: Evaluation of Composting Implementation. Prepared for: U.S. Army Toxic and Hazardous Materials Agency. Prepared by: Remediation Technologies, Inc. Concord, Massachusetts.
- Rynck, R. *editor* (1992) On-Farm Composting Handbook. Northeast Regional Ag. Experiment Stations. (NRAES) Ithaca, NY
- Schnürer, J. and T. Roswall (1982) Fluorescein Diacetate Hydrolysis in soil and litter. Appl. Env. Microbiol. 43:1256-1261
- Sikora, L. et.al. (1983) Laboratory Composter for Simulation Studies. J. Environ. Qual. v12-2:219-224. USDA, Beltsville MD.
- Smith, L.L. et.al. (1980) Biological Treatment for Waste Streams From Propellants and Explosives Manufacturing. Hercules Inc., Radford Army Ammunition Plant,

- Radford, VA. 2nd Jt. Symp. "Compatibility of Plastics/Materials with Explosives" and "Processing Explosives" Blacksburg, VA 14-16 Oct. 1980
- Suler, D. (1979) Composting Hazardous Industrial Wastes. 1979 Conference on Composting and Waste Recycling Philadelphia, Pennsylvania May 2-4, 1979. Compost Science/Land Utilization 20(4), 25-27, Publ: Jul-Aug
- Tan, E.L. et. al (1992) Mutagenicity of Trinitrotoluene and Its Metabolites Formed During Composting. J Toxicology & Env Health, Jul 92, v36, n3, p165 (11).
- TVA (1991) Process and Economic Feasibility of Using Composting Technology to Treat Waste Nitrocellulose Fines. Report# CETHA-TE-CR-91012. U.S. Army Toxic and Hazardous Materials Agency. Prepared by: Tennessee Valley Authority, Muscle Shoals, Alabama.
- Weston, Inc. (1985) Literature Review-- Microbial Degradation and Land Farming of Pink Water. Report to U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Grounds, Maryland 21010
- Weston, Inc. (1988) Field Demonstration Composting of Explosives-Contaminated Sediments at the Louisiana Army Ammunition Plant (LAAP). September, 1988 Report# AMXTH-IR-TE-882428, Roy F Weston Inc. Report to U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Grounds, Maryland
- Weston, Inc. (1989) Task Order - 12 Field Demonstration Composting of Propellants Contaminated Sediment at the Badger Army Ammunition Plant (BAAP) Report# CETHA-TE-CR-89061. U.S. Army Toxic and Hazardous Materials Agency. Prepared by: Roy F. Weston, Inc. West Chester, Pennsylvania 19380.
- Weston, Inc. (1989) Composting of Explosives Contaminated Soil Technology. 1989 Report# CETHA-TE-CR-90027, Roy F Weston Inc. report to U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Grounds, Maryland 21010
- Weston, Inc. (1990) Test Plan for the Composting Optimization Field Study at Umatilla Army Depot Activity (UMDA). Roy F Weston Inc. report to U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Grounds, Maryland
- Weston, Inc. (1991) Final Report: Optimization of Composting for Explosives Contaminated Soil. Work Order # 2281-08-10 Roy F Weston Inc. report to U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Grounds, Maryland



Weston, Inc. (1992) Test Plan for Seeding and Windrow Composting Field Studies at Umatilla Army Depot Activity (UMDA). Roy F Weston Inc. report to U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Grounds, Maryland

Weston, Inc. (1993) Final Report: Windrow Composting Demonstration for Explosives Contaminated Soil. Report# CE-TNA-TS-CR-43043 Roy F Weston Inc. prepared for U.S. Army Toxic and Hazardous Materials Agency,

Woods End Research Laboratory. (1993) Quick-Test Procedures for Compost Quality Monitoring. *manuscript*

Woodward, R.E. (1990) Evaluation of Composting Implementation: A Literature Review Report # TCN 89363; U.S. Army Toxic and Hazardous Materials Agency

S.G. Wilson et. al. (1990) Development of a Colorimetric, Second Generation Nucleic Acid Hybridization Method for Detection of Salmonella in Foods and a Comparison with Conventional Culture Procedure J. Food Science 55: 1394-1398

U.S EPA (1985) Pathogen Risk Assessment Feasibility Study U.S. EPA/600/6-88/003, U.S. EPA Washington D.C.

U.S EPA (1993) Code of Federal Regulations Standards for the Use or disposal of Sewage Sludge. 40 CFR 503, Federal Register, Vol 58-No. 32 February 19, 1993

US EPA (1986) Test Methods for Evaluating Solid Waste: Physical/Chemical Methods. 3rd Ed. Publ. No. SW-846 Office of Solid Waste and Emergency Response, Washington DC

US Food & Drug Administration (1976) Bacteriological Analytical Manual. Washington DC

USGS (1992) The Preparation and Analysis of Soil Compost Material for Inorganic and Explosive Constituents. Report# CETHA-TS-CR-92067. U.S. Army Toxic and Hazardous Materials Agency. Prepared by: U.S. Geological Survey, Denver, CO